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FALL REGROWTH OF CRESTED WHEATGRASS AND FOURWING SALTBUSH

by

Noor Mohammad

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Range Science

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1981

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Noor Mohammad

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ABSTRACT

Fall Regrowth of Crested Wheatgrass

and Fourwing Saltbush

by

Noor Mohammad, Doctor of Philosophy

Utah State University, 1981

Major Professor: Dr. Cyrus M. McKell
Department: Range Science

During 1980-81, studies with crested wheatgrass (Agropyron desertorum) and fourwing saltbush (Atriplex canescens) were conducted in controlled environment growth chambers as well as under field conditions to achieve the following objectives:

1. To determine the effect of nitrogen fertilizer on the water use efficiency.

2. To determine the effects of various temperature, water stress and nitrogen treatments on the productivity, nitrogen content and carbohydrate reserves.

3. To determine the effects of N fertilization on fall and spring regrowth.

Crested wheatgrass and fourwing saltbush plants were maintained in three growth chambers for 60 days under three temperature regimes (11/7, 19/7 and 27/7 C), two soil moisture stress regimes (-0.3 bars and -15 bars) and three N fertilizer levels (0, 50 and 100 kg of N/ha).

During the study, tranpiration and plant biomass data were recorded.

During the first week of September, 1980, crested wheatgrass and fourwing saltbush pastures at Nephi, Utah, were subjected to three nitrogen fertilizer levels (0, 50 and 100 kg N/ha). After 60 days the fall regrowth was clipped. In the first week of June 1981 spring regrowth of both species was measured. In the fall of 1981, a second experiment was laid out at Nephi where crested wheatgrass and fourwing saltbush plants were subjected to three soil moisture regimes (dry, medium and wet) and three nitrogen fertilizer levels. At the end of a 60 day study period, dry matter yield, root distribution, water content and soil samples at different incremental soil depths were collected.

Under controlled environment conditions, the water use efficiency of both species was six percent more with the application of a moderate amount of nitrogen (50 kg/ha). A high temperature regime (27/7 C) and a high water stress regime (-15 bars) increased the water use efficiency of plants by eight and six percent respectively.

Results of the growth chamber experiment revealed that nitrogen fertilization had a significant effect on plant biomass, nitrogen percent and total nonstructual carbohydrate reserves of crested wheatgrass and fourwing saltbush. The data further suggested that nitrogen fertilization can substitute for the adverse effects of low temperature and low soil moisture on plant growth.

Nitrogen fertilization during fall increased plant biomass, nitrogen percent and total nonstructural carbohydrate reserves in crested wheatgrass and fourwing saltbush. Fall fertilization did not reduce spring regrowth.

It is inferred that under limited soil moisture and low temperature during the fall growing season, a moderate amount of nitrogen fertilizer (50 kg N/ha) may increase the forage availability and water use efficiency of crested wheatgrass and fourwing saltbush to the level of plants maintained at moderate temperature and adequate soil moisture. Nitrogen fertilization (50 kg N/ha) of crested wheatgrass and fourwing saltbush during fall does not reduce plant nitrogen percent or carbohydrate reserves which may limit spring regrowth.

(116 pages)

INTRODUCTION

Nature of the Problem

In the western United States, forage availability and quality is minimal during the fall grazing season and any fall regrowth is welcomed by livestock producers. The often short period of favorable growth is restricted by limited moisture conditions which restrict the time for the plants to complete a normal phenological cycle. Soil moisture also influences the growth of the plants by affecting the concentration of readily soluble nutrients. The degree of water stress and the specific stage of plant growth during which it occurs also has a positive or negative influence on carbohydrate reserve levels.

Information on the amount of dry matter accumulation and nitrogen use efficiency relative to temperature during fall regrowth is of importance with regard to the effective use of residual soil nitrogen and the potential benefits of a fertilization program. Whether nitrogen fertilization under specific environmental and biological conditions stimulates regrowth and carbon, nitrogen concentration in shrubs and grasses during fall is not well known.

Crested wheatgrass (*Agropyron desertorum* (Fisch. Schult) and four-wing saltbush (*Atriplex canescens* (Pursh.) Nutt.) are useful species for studying the effects of different physical variables and nitrogen fertilization on productivity, nitrogen content and carbohydrate reserves because of their widespread use and distribution. Crested wheatgrass has been extensively seeded to replace big sagebrush

(Artemisia tridentata Nutt) in the western United States. It is a vigorous, drought resistant and palatable species. It provides forage for livestock during the short fall regrowth period if enough soil moisture is available. If soil moisture limits fall regrowth, the forage available from crested wheatgrass consists only of old residue.

Fourwing saltbush is one of several species that could be used for replacing big sagebrush in the arid west. Because fourwing saltbush often grows naturally on relatively dry, saline areas, this species may have special characteristics that enable it to be a useful forage species for use under conditions of limited moisture. Therefore, replacement of big sagebrush by fourwing saltbush in shrub grass rangelands would provide a better forage mixture for optimum exploitation of the ecosystem.

Manipulation of physical factors such as temperature and light under range situations is beyond management control. Artificial irrigation is also not feasible on rangelands. However, fertilization may provide a good opportunity to increase the effectiveness of early fall rains to produce needed forage without having a detrimental effect on plant reserves needed for subsequent initiation of spring growth.

So far, range forage research studies have concentrated on spring and summer growth patterns in grasses and very little work has been done to study the nature and control of fall regrowth. A concerted effort is needed to explore avenues for increasing fall regrowth for enhancing forage during fall and winter seasons when forage is in short supply.

The general objectives of this thesis was to determine whether nitrogen fertilization can compensate for the adverse effects of low temperature and high water stress on the fall regrowth of crested wheatgrass and fourwing saltbush.

The following specific hypotheses were tested:

1) Nitrogen increases water use efficiency in crested wheatgrass more than fourwing saltbush.

2) Nitrogen fertilization can compensate for adverse effects of low temperature and high water stress on the growth of crested wheatgrass and fourwing saltbush by increasing:

a) Plant biomass

b) Nitrogen content

c) Carbohydrate contents

3) Nitrogen fertilization increases fall regrowth but does not adversely affect subsequent spring regrowth in crested wheatgrass or fourwing saltbush.

REVIEW OF LITERATURE

General Characteristics of Crested Wheatgrass and Fourwing Saltbush

Crested wheatgrass

Crested wheatgrass is native to Siberia and was introduced in the United States in 1927 (Rogler and Schaaf 1963). Since then it has been widely seeded throughout the northern Great Plains and Intermountain areas of the United States. Crested wheatgrass has several attributes that have led to its wide acceptance and use. It is an easily established vigorously growing bunchgrass that is resistant to grazing, drought, high and low temperature and furnishes excellent forage for livestock (Houston 1957).

Agropyron cristatum has been extensively used in planting mixtures with *Agropyron desertorum*. Swallen and Rogler (1950) have listed the following characteristics of *Agropyron cristatum* by which it can be differentiated from *A. desertorum* (Table 1).

Table 1. Taxonomic characteristics of *Agropyron desertorum* and *A. cristatum* (after Swallen and Roger 1950).

Agropyron desertorum	*Agropyron cristatum*
Glumes with broad hyaline margins, abruptly narrowed into the awn, not at all contorted, spikelets relatively broad, ascending or appressed, not crowded on the axis; blades glabrous or scabrous on the upper surface.	Glumes with narrow margins gradually tapering into the awn, more or less contorted, at least in drying; spikelets narrow, horizontally spreading, crowded on the axis; blades usually conspicuously pilose on the upper surface.

Fourwing saltbush

Fourwing saltbush is one of the most widely distributed and important forage shrubs on western ranges. Springfield (1970) reviewed the present state of knowledge relating to the germination and establishment of fourwing saltbush. It provides high quality forage for herbivores and is among the most desirable shrubs in the southwestern United States. Fourwing saltbush is used by all classes of livestock as well as wildlife because of its availability and persistence during the winter (Blauer et al. 1976, Bidwell and Wooton 1925, Trumble 1932).

Mature fourwing saltbush plants are commonly less than 2 m tall with stems freely branching above the ground surface. The extensive root system may penetrate 5 to 15 m into alluvial soils, making the plant very drought resistant and well-suited to erosion control (Williams and O'Connor 1973). Important characteristics of fourwing saltbush are summarized in Table 2 (Institute for Land Rehabilitation 1979).

Plant Productivity

Many environmental factors such as water, temperature, nutrients and photoperiod influence the magnitude of photosynthates available for current growth and for regrowth. The internal water balance of plants control most of the physiological processes within plants. Lauenroth and Dodd (1979) reported that water was an important factor limiting legume populations and productivity in shortgrass prairies. They noticed that water application greatly increased both the density and biomass of legumes, presumably due to more favorable

Table 2. General characteristics of fourwing saltbush (from Institute for Land Rehabilitation 1979).

CHARACTERISTICS	OBSERVATIONS
Height	0.6 to 2 m
Spread	0.3 to 2.4 m
Growth form	Decumbent to erect, deciduous to evergreen shrub
Root system type	Deep, extensive
HABITAT	
Distribution	Canada to Mexico, Great Plains to Pacific Coast Ranges
Elevation	Sea level to 2440 m
Topography	Dry slopes, flats, washes valley bottoms
Salt tolerance	Excellent
Drought tolerance	Excellent, 15 to 30 cm precipitation
Soil	Well drained, alkaline, medium to coarse textured
PROPAGATION	
Seed	Harvest mid-October through April, germination improved by scarification and dry storage.
Vegetative	Stem cuttings root well in spring and summer, treat cuttings with 0.3% IBA powder.

conditions for nitrogen fixation and increased competitive advantage under nitrogen deficient conditions.

Effect of soil moisture and temperature

A few attempts have been made to evaluate the effects of water stress on the productivity of range plants. Ellern (1976) found that efficiency of water use by Indian ricegrass (*Oryzopsis hymenoides*) generally increased with increasing moisture tension. Mott and McComb (1975) determined that under high moisture stress both shrubs and grasses reduced plant dry weight, number of flowers, and seeds. In sunflower, leaf growth occurred only when leaf water potentials were above -3.5 bars (Boyer 1968). Majerus (1975) ranked three mixed-prairie grass species as to their growth tolerance to decreasing soil moisture potential. Blue grama (*Bouteloua gracilis*) was highest followed by western wheatgrass (*Agropyron smithii*) and little blue stem (*Schizachyrium scoparium*). He found significant differences in leaf and root growth response to soil water potential. Soil water potential developed by bluegrama at the cessation of leaf growth ranged from -80.0 bars at 5 cm depths to -8.4 bars at 35 cm depths, while corresponding values for little bluestem were -24.3 and -3.0 bars, and -30.0 and -15.3 bars for western wheatgrass, respectively.

The amount and rate of water uptake depend on the ability of the roots to absorb water as well as the ability of the soil to supply and transmit water toward the root. These, in turn, are related by properties of the plant: rooting density, root depths, and rate of root extension, as well as the physiological ability of the plant to decrease its water potential sufficiently to continue drawing water from the soil at a rate needed to avoid wilting (Hsiao 1973).

Water use, shoot and root production and root/shoot ratios for creosotebush, (Larrea sp), mesquite (Prosopis glandulosa), broom snakeweed (Xanthocephalum sarothrae) and fourwing saltbush were studied by Dwyer and Degarmo (1970) under four soil moisture regimes. Fourwing saltbush required the least amount of water per gram of total shoot and root produced of the four shrubs studied. The highest production for shrub and grass species occurred at the field capacity moisture level and the lowest production occurred at one-third of field capacity. Under the same treatments, bush muhly (Muhlenbergia porteri) produced the highest total root and shoot biomass at field capacity followed by blackgrama (Bouteloua eriopoda), mesa dropseed (Sporobolus flexuosus) and tobosa grass (Hilaria mutica). In general, shrubs were less efficient in water use than grasses.

Clipping of plants before stress increases herbage production (Wisiol 1979). Baker and Hunt (1961) studied the influence of clipping on the growth of intermediate wheatgrass (Agropyron intermedium) and pubescent wheatgrass (A. trichophorum) under drought stress. They found significant differences in dry matter yield between the plants maintained at field capacity and those maintained just above the wilting point. Mohammad (1979) drew the following conclusions from a greenhouse study on responses of crested wheatgrass and Russian wildrye (Elymus junceus) to different levels of water stress and defoliation:

1. Light defoliation (40 percent) under soil moisture field capacity results in greater plant production than undefoliated plants maintained at either field capacity or wilting point.

2. The influence of water stress on root production is more prominent than the intensity of defoliation.

3. Undefoliated and 40 percent defoliated plants growing under a moisture stress of -5 bars were able to recover when soil moisture was raised to field capacity. However, plants under 80 percent defoliation and -15 bars water stress showed no regrowth during the 40-day recovery period.

There are implications that temperature and relative humidity of the atmosphere also play a significant role in the physiological ability of plants to maintain low water potential (Eddleman and Nimlos 1972). In Laude's (1957) study of the competitive ability of range grasses and weeds in relation to soil temperature, the emergence of five winter annual grasses decreased over 90 percent as soil temperature increased from 46 to 49 C. In a comparison of a heat-tolerant perennial grass, nodding stipa (Stipa sp.) and a warm season weed, rough pigweed (Chenopodium sp.), the pigweed was able to tolerate higher soil temperatures than the nodding stipa.

Blaisdell (1958) observed that growth and development in grasses during the early part of the growing season are closely correlated with soil temperature. Pearson (1979) obtained the maximum productivity of Indian ricegrass when 1) soils warmed up early in the spring 2) temperatures were low later in the spring, and 3) additional water was supplied during the spring growth period.

Sweeney and Hopkinson (1975) conducted an experiment with 19 tropical pasture plants in a controlled temperature greenhouse to determine the amount of dry weight accumulating during early vegetative growth in relation to temperature. Eight combinations of day/night temperatures with 3 C increments from 15/10 to 36/31 C were used. They found that vegetative growth decreased when temperatures fell below 30/25 C. At 15/10 C relative growth rates never exceeded about 1/3 of the recorded maximum. The ratio of root to total dry weight tended to fall as relative growth rate rose.

The literature reviewed indicates that temperature and soil moisture play important role in growth. Most of the studies reported here are results of research work on summer ranges. No study has been conducted to identify the effects of physical variables on range plants during the fall regrowth period. Research is needed to identify the role of soil moisture and temperature in restricting fall regrowth during a very short period.

Influence of N fertilization

Nutrient deficiency, primarily nitrogen (N), is a major plant growth limiting factor. There are no reports of research to explore the effects of N fertilization on fall regrowth of range plants. However, various studies conducted on fertilization of summer ranges indicate improvement in forage quality, quantity and palatability (Wight 1976) and earlier growth in the fall (McKell et al. 1959).

Williams et al. (1956) recommended fertilization of ranges to reduce competition from undesirable annual weeds and encourage more desirable species. Nitrogen fertilization stimulates vigorous growth of desirable grass species but can greatly increase the growth of annual weeds.

Greatest increases in total dry matter yields for a given increment of fertilizer were observed with a 67 kg N/ha application to blue grama (Goetz 1969). Nitrogen fertilization increased herbage production, crude protein content, and utilization by cattle in mixed prairie in Wyoming (Samuel et al. 1980). Dwyer (1971) applied 0, 45 and 67 Kg N/ha annually for 6 years to blue grama range in south central New Mexico and found grass production was significantly increased over control.

In general moisture additions have been less effective in increasing herbage yields than have nitrogen additions (Klages and Ryerson 1965; Smika et al. 1965). However, the combination of added nitrogen and added water greatly increases herbage yields. Nitrogen addition also increases moisture-use efficiency, perhaps in part because added nitrogen stimulates greater root exploration of the soil mass (McKell et al. 1962, Lorenz and Rogler 1966, Houston and Hyder 1975).

Nitrogen fertilizer increased rye grass (Lolium sp) production and in combination with a wetting agent it further enhanced the establishment of ryegrass (Debano and Conrad 1974). Similar results were found by Sneva (1973) while studying the responses of crested wheatgrass to nitrogen and clipping over a period of 13 years. In another study on crested wheatgrass fertilization, Power and Alessi (1970) obtained 380-490 kg N/ha more forage when nitrogen was applied in combination with irrigation.

McKell et al. (1959) studied the effects of fertilization on the soil moisture use on California annual ranges. Fertilization resulted in greater forage production and earlier feed than without fertilization. Plants extracted more soil moisture as a result of the application of nitrogen. However, application of nitrogen significantly increased water use efficiency. Seamonds and Lang (1960) found significant increase in the production of old crested wheatgrass stands as a result of N fertilization during the growing season when the soil moisture was adequate.

Research work on summer ranges shows significant improvement in the quantity and quality of forage with the application of nitrogen fertilizer when temperature and soil moisture are adequate for plant growth. However, effects of nitrogen fertilization during fall under low soil moisture and low temperatures have not been studied. Nitrogen addition stimulates plant growth during summer growth season. A needed area of investigation is whether nitrogen can also be effective in increasing the dry matter yield under low soil moisture and low temperature environmental conditions.

Plant Nitrogen Content

Effect of soil moisture and temperature

Generally total uptake of nitrogen by plants increases in the presence of adequate soil moisture (Doss and Scarsbrook 1969, Fernandez and Laird 1959). At the same time, however, the percentage of nitrogen in plant tissues decreases with increases in moisture (Humphries 1962, Macleod 1965).

Moisture stress at a particular physiological stage has a definite relation to nitrogen content of the plant. Storrier (1965) noted that when wheat was irrigated after anthesis a decrease in N content was normally shown by the maturing wheat crop. Irrigation during jointing and milking stages increased the uptake of mineral nitrogen by the crop.

Soil temperature alters the content and form of nitrogen compounds as it affects both ammonification and nitrification. Ammonification and nitrification take place from 5 to 40 C with an optimum at 30 to 35 C for many soils (Gardner 1965). Effect of soil temperature on N availability was studied by Scarsbrook (1965) who noted that N availability was reduced in cold soils.

Duncan et al. (1979) grew six cool-season and two warm-season grasses in controlled environment chambers under cool or warm temperature regimes. The effect of warm or cool temperatures on percent N absorbed was different for warm and cool-season grasses. Only two species accumulated nitrate in the cool temperature but all warm season grasses accumulated nitrate under warm temperatures.

This controversial issue suggests that research is needed to determine the effects of low temperatures and soil moisture on the nitrogen content of plants. In this thesis an attempt will be made to quantify the nitrogen contents as influenced by temperature, water stress and nitrogen fertilization.

Influence of N fertilizer

Nitrogen fertilization generally increases protein content of species regardless of level of treatment; the magnitude of increase, however, varies greatly among sites and species (Smika et al. 1960). Higher nitrogen percentages were found on plots of bluestem receiving additional nitrogen than on plots receiving only moisture or the control (Owensby et al. 1970).

Nitrogen fertilization also increased the dry matter yield and nitrogen content of tropical para grass (Brachiaria mutica) but the yield rate leveled off at the higher rates of nitrogen (Bishop 1977, Chadhokar 1978).

Rains et al. (1975) studied the effects of N fertilization, burning, and grazing on nitrogen reserves of big bluestem in the Kansas Flint Hills. Nitrogen reserves were lowered when growth exceeded photosynthetic production and nutrient assimilation. However, nitrogen in storage organs increased linearly as nitrogen fertilization was increased. Increasing the grazing rates when nitrogen fertilization was increased had little effect on N reserves at senescence.

The effects of water and nitrogen treatments on nutritional characteristics of blue grama were studied by Bokhari (1978) on a native short grass prairie site in northeastern Colorado. Results indicated greater total nonstructural carbohydrate, protein, gross energy and total carbon are contained in herbage from irrigated and from irrigated plus nitrogen fertilized sites than from the non-irrigated or sites fertilized with only nitrogen.

Nitrogen fertilization on range plants has shown an increase in the nitrogen contents of range plants. However, the effect of nitrogen addition during the short fall regrowth period and its influences on the nitrogen reserves of plants has escaped investigation. In the present study an attempt will be made to specify the minimum nitrogen fertilizer requirements for stimulating the fall regrowth and its effects on the nitrogen content of plants.

Carbohydrate Reserves in Plants

The major source of energy for maintenance, growth and reproduction in plants is considered to be present in the carbohydrate fraction of the organic compounds (Khan 1980). Carbon assimilation by plants in excess of their demands for growth and metabolism provides for carbohydrate reserves. These energy reserves are stored in various vegetative organs of annual and perennial forage plants.

Many review articles and reports have emphasized the function of carbohydrate reserves during regrowth in the spring, fall or following defoliation under different environmental conditions (Menke 1973, White 1973, Trlica and Cook 1972). Reserves may be utilized anytime that photosynthesis cannot meet the current demands of the plant. When sufficient photosynthetic tissue has been produced so that carbohydrate production exceeds growth, reserve carbohydrate levels increase.

Accumulation of reserve carbohydrates continues until defoliation, phenological changes, or dormancy necessitate carbohydrate utilization above normal growth and maintenance requirements. During dormant periods, respiration demands gradually lower reserves. Initiation of new growth following dormancy rapidly depletes reserve levels.

Effects of soil moisture and temperature

Periods of water stress tend to increase the concentration of carbohydrate reserves in plants (Brown and Blaser 1970, Maranville and Paulsen 1970, Sosebee and Wiebe 1971, Trlica 1971, Dina and Klikoff 1973). Trlica and Cook (1972) reported that fall regrowth of crested wheatgrass and Russian wildrye was stimulated either by natural rainfall or irrigation and caused a reduction in reserves. Carbohydrate levels increased in the herbage of Bermuda grass (*Cynodon dactylon*) and in the stubble and herbage of orchard grass (*Dactylis glomerata*) when growth was retarded by water stress (Blaser et al. 1966, Ward and Blaser 1961).

Dina and Klikoff (1973) studied the effects of plant water stress on carbohydrate reserves of big sagebrush. They found that the starch content did not change significantly in water stressed plants, although the sugar content increased significantly in leaves, stems and roots. They suggested that sugar increases in the stems, leaves and roots of sagebrush might be of significance as sugars might protect the RNA-DNA complex, as well as enzymes, during water stress. They suggested that if concentration of sugars did not increase, cellular injury might occur.

If accumulation of sugar is an important factor in the resistance of plant organs to water stress, then continued translocation would appear to be important in the survival of storage organs such as rhizomes and roots which are distant from the site of assimilation. However, protection of the photosynthetic apparatus would necessitate a slowing down in the transfer of assimilates away from the chloroplasts (Santarius 1967). Possibly the balance between retention of sugars by the chloroplasts and transfer of sugars to the conducting system will in part dictate the response of plants to water stress. Maranville and Paulsen (1970) found an increasing concentration of low molecular weight carbohydrates in corn (Zea mays) seedlings subjected to moisture stress. They concluded that this would probably help plants retain turgidity and protect protoplasmic constituents.

Laude (1964) reported that prairie grass seedlings subjected to 42 C and 30 to 35 percent humidity (heat and drought stresses) showed a rapid decrease in tolerance that might be associated with the exhaustion of food reserves in the endosperm.

Literature is lacking in research work in the role of low temperature and high water stress in maintaining carbohydrate reserves during short fall regrowth period. Therefore, a study to investigate the relationship between TNC and low temperature and low soil moisture is imperative if efforts are made to stimulate the fall regrowth. Total nonstructural carbohydrates are important sources of available energy and are required for initiation of spring regrowth. The present work will clarify the status of reserves under various environmental combinations at the termination of fall regrowth.

Influence of N fertilization

Pettit and Fagan (1974) applied five rates (0, 30, 60, 90 and 120 kg of N/ha) of nitrogen fertilizer to a buffelgrass (Cenchrus ciliaris) pasture to determine the influence of fertilizer on carbohydrate reserves. In the first year of study the carbohydrate reserve concentration in the storage tissues varied inversely with the rate of nitrogen application under the past-ripe phenological stage. After this date, TNC's accumulated more rapidly in the higher N treatments. They further reported that on all sampling dates buffelgrass crowns contained more reserve carbohydrates than did the roots. Similarly, stolons contained 19 percent more reserve carbohydrate than did the crowns. Shrubs like snowberry (*Symphoricarpus oreophilus*) also show a generally larger pool of TNC in stems than in the below ground biomass (George and McKell 1978).

Carbohydrate reserves in relation to growth stage were studied by Coyne and Cook (1970) for eight desert range species. Results indicated that maximum plant vigor in relation to carbohydrate reserves depends upon reserve storage. They noticed that carbohydrate concentrations were consistently higher in the roots of the five woody species than in the crowns at the end of the growth period.

The research work reviewed indicates that effects of nitrogen fertilization on range plants vary from one specie to the other. In addition all of research work reported here is applicable to summer ranges.

Whether nitrogen fertilization in the late fall period increases or decreases the carbohydrate reserves of crested wheatgrass and fourwing saltbush is still a controversial issue to be further investigated. This parameter is of significance particularly when much emphasis is given to fertilization for increasing the dry matter yield of rangelands and also extending the growing period.

METHODS AND PROCEDURES

Growth Chamber Experiment

Among the most important physical variables affecting fall regrowth are light, temperature and soil moisture. Control of these factors under field conditions is not feasible. However, some environmental conditions which control fall regrowth can be simulated in a growth chamber to determine their influences and interaction with nitrogen fertilization. This experiment was conducted to test hypothesis numbers one and two stated earlier.

Origin of plant materials

At the Tintic Range Research Area, located 5 kilometers west of Eureka, Utah, stands of sagebrush and juniper were converted to crested wheatgrass in the early 1950's. In some of the present crested wheatgrass stands, sagebrush reinvaded. Pastures in the area presently consist of those dominated by sagebrush, by crested wheatgrass and some with mixed stands of sagebrush and crested wheatgrass. During the last 30 years the pastures have been grazed by livestock. Renewed research efforts are underway to improve the pastures by developing and applying modern technology.

To relate the growth chamber study back to the field situation, soil from the Tintic pastures was used in the research. A quantity of the top 20 cm of soil from the southeastern corner of the old exclosure in pasture 8 was obtained and returned to the laboratory for analysis and filling of plant growth containers. The top 20 cm of soil had a pH of 7.9, which was suitable for plant growth. Chemical analysis indicated the soil contained 6.3, 2.0, 1.6 and 4.0 me/100 g of phorphorus, potassium, sodium and calcium plus magnesium, respectively. The concentration of each of these elements was considered sufficient for plant growth. Total nitrogen content of the soil was 0.10 percent which was below the normal nitrogen requirement for most agricultural crops. However, nitrogen requirements for fall growth of range grasses has not been studied. The nitrogen levels selected for this study were based on summer range research work.

The top 20 cm of soil was chosen because this is the major soil stratum of mineral concentration, roots and microbial activities for both species. Greenwood and Brotherson (1978) suggested using the upper 13 cm of the soil profile for mineral concentration. However, Ludwig (1969), in a study of the different foothill communities in Utah, showed that the upper 10 cm of soil contained 80 percent of the mineral concentration. In desert shrub communities more than 50 percent of the fine roots (those most likely to absorb soil materials) are found concentrated in the upper 15 cm of the soil profile (Holmgren and Brewster 1972). Sturges and Trlica (1978) reported that approximately 60 percent of the total root system in big sagebrush was located in the surface 30 cm of soil.

The soil samples were air dried and screened through 5 mm wire-mesh. Paper cartons (10x10x20 cm) were filled to 17 cm depth with the soil and weighed.

Pasture 8 from where dormant clones of crested wheatgrass were obtained has been under grazing use since 1956. From 1956 to 1964, the pasture was grazed by sheep with about 40 percent utilization level. Since 1964 it had been irregularly grazed by sheep and cattle. During the summer of 1980, the pasture was grazed with cattle.

Grazed crested wheatgrass clones were collected from Tintic pasture no. 8, outside the old exclosure during the late summer dormant period. The root systems of these crested wheatgrass plants were washed and individual clones of unknown age were transplanted into the paper cartons containing soil from the Tintic area. Moisture in all containers was raised to field capacity and containers were kept in the greenhouse for three days before initiating the treatments (Figure 1).

One-year old plants of fourwing saltbush grown from cuttings in plastic containers maintained at field capacity and fertilized initially with a low level NPK fertilizer (20:20:20) were transplanted into the paper cartons. Before transplanting, the root systems of fourwing saltbush plants were carefully washed. The transplanted clones were grown in cartons filled with the Tintic soil for 60 days before transferring them to growth chambers. This provided time to reduce the previous effect of fertilization or growth.

<u>Control of light and temperature regimes</u>

Temperature regimes selected for the growth chamber experiment corresponded with the average Nephi field temperatures recorded during fall season. Temperature at Nephi during the fall varies from 33/13 to 7/-3 C during the August-November period. Therefore,

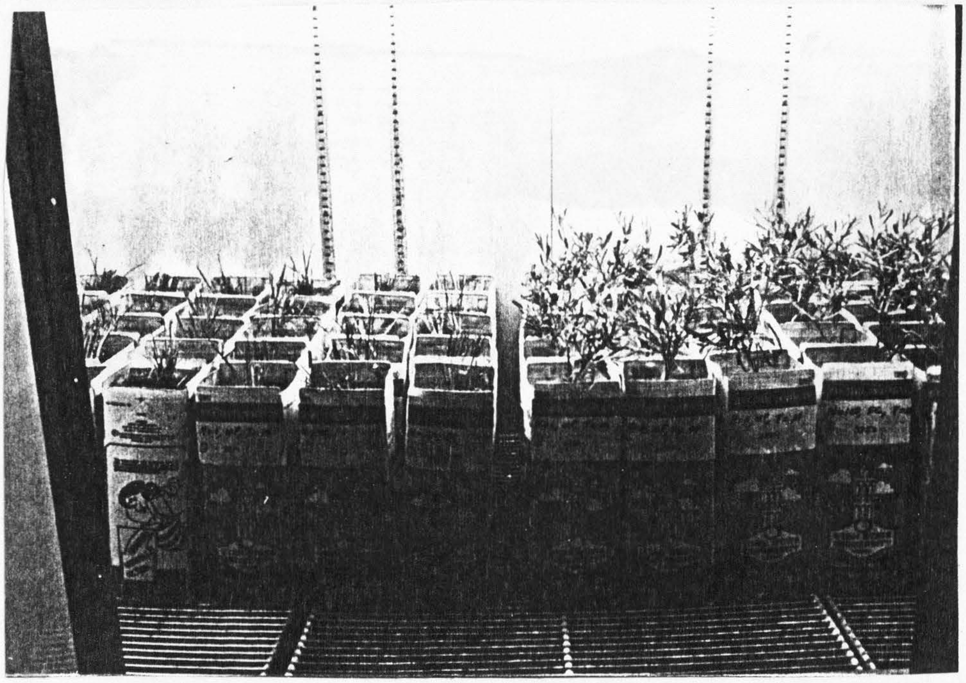

Figure 1. Crested wheatgrass and fourwing saltbush plants subjected to three temperature regimes, two water stress and three N fertilizer levels in growth chambers.

to simulate the temperature patterns during fall regrowth, 27/7, 19/7 and 11/7 C day/night temperatures with a 12-hour photoperiod and photosynthetic photon flux density of 400 microeinsteins m^{-2} sec^{-1} were chosen as experimental conditions. The day temperature regimes of 27, 19 and 11 C corresponded with the maximum and minimum temperature data observed at Nephi Dryland Research Station. However, as the night temperatures become low during the fall growing season and literally very little growth takes place during night, a constant low temperature of 7 C was maintained during night to provide a minimum temperature regime for plants. The twelve-hour photoperiod corresponded with the 12 hour day and 12 hour night period during this season. Photosynthetic photon flux density of 400 microeinsteins m^{-2} sec^{-1} was considered adequate for plant growth. Bokhari (1976) and Khan (1980) used a photosynthetic photon flux density of 350 and 400 microeinsteins m^{-2} sec^{-1} in growth chamber experiments, respectively. However, intensity of light under field conditions is much higher than in the growth chambers and it is not feasible to achieve such standards.

Maintenance of soil moisture regimes

Two soil moisture regimes of approximate field capacity and wilting point percentage were selected for the growth chamber experiment. Field capacity of the mixed soil was determined by water soaking of ten containers filled with preweighed, dry mixed soil. After a period of 48 hours of free drainage, the soil in the containers was weighed. The difference in weight between the dried and free drainage soil was used as the amount of water present in this particular soil at field capacity. A soil water potential release curve of the soil was determined by the Soil Analysis Laboratory, Soil Science Department, Utah State University using standard laboratory procedures (Richards, 1954). Soil moisture percentages for field capacity and wilting point regimes were obtained from the soil water potential curve (Figure 2).

Field capacity (14.7 percent soil moisture) and wilting point (7.5 percent soil moisture) corresponding to -0.3 bars and -15 bars, respectively, were approximated by watering of plants at 48 hour intervals. Evaporative water loss from the containers was reduced by wrapping the soil surface of each container with a plastic wrap. To partially overcome having a gradient in soil moisture content from the soil surface downward when the containers were irrigated, a perforated plastic tube, 1 cm inside diameter, was pushed about 12 cm deep into the soil of each container. When the containers were weighed an amount of water equal to that which was lost through transpiration during the last 48 hours was added through the tube. A cork was immediately inserted in the tube to avoid evaporation.

Soil moisture regimes of field capacity and wilting point ranges for each temperature regime were calibrated from a soil water potential curve developed in the laboratory (Figure 2). At 27/7 C temperature, the field capacity soil moisture regime varied from $-\frac{1}{2}$ of $-\frac{1}{4}$ bars. The corresponding values for wilting point regime were -14 and -18 bars. The field capacity and wilting point ranges at 19/7 C were $-\frac{1}{2}$ to minus one and -13 and -17 bars respectively. The variation in the field capacity regime was further reduced between $-\frac{1}{2}$ and -1/5 bars at

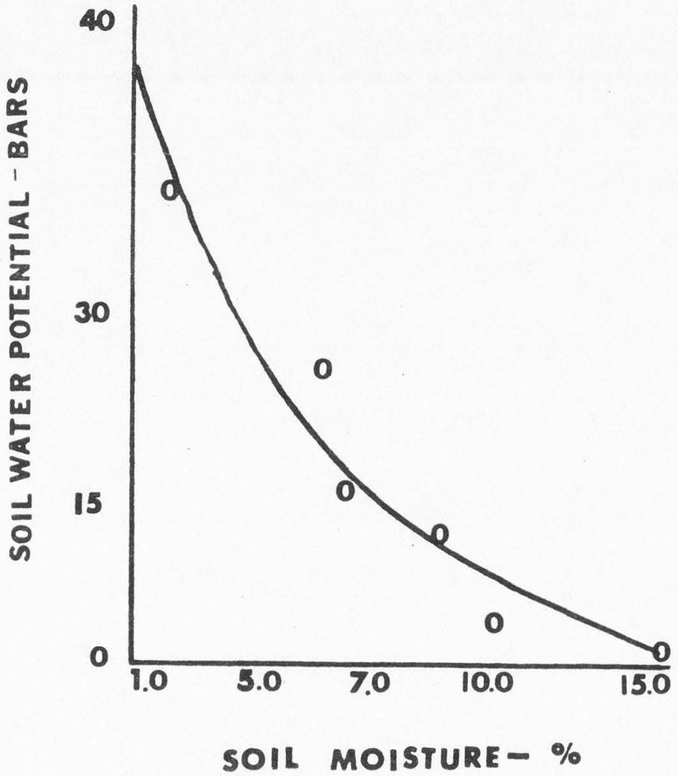

Figure 2. Relationship between soil moisture percent by weight and soil water potential (-bars) as determined for soil obtained from the Tintic study area.

11/7 C. The wilting point soil moisture regime varied from -14 and -16 bars at 11/7 C.

At the end of the 60-day study period, root systems of crested wheatgrass and fourwing saltbush that had been maintained at field capacity and wilting point soil moisture regimes were examined. Both crested wheatgrass and fourwing saltbush roots were well distributed within the pots under the field capacity soil moisture regime. However, under the wilting point regime, crested wheatgrass roots concentrated around perforated plastic tube. Therefore, uniform distribution of water in pots under the wilting point soil moisture regime was not obtained. However, the amount of water applied was fully utilized by roots due to minimum evaporation from the plastic-sealed surface of pots.

Nitrogen fertilization

Both crested wheatgrass and fourwing saltbush plants were subjected to the three nitrogen treatments (0, 50 and 100 N kg/hectare). A preweighed amount of ammonium nitrate was dissolved in distilled water and poured into the containers at the beginning of the study. No additional fertilizer was applied during 60-day study period. The actual amount of N fertilizer per plant was determined by standard procedures that involved adding the nitrogen at the rate applied to a field 15 cm layer of soil. The nitrogen application rates corresponded with the nitrogen fertilizer levels used in the field experiment.

Data collection

Productivity measurements were made by harvesting the plants at the end of the 60-day study period. The clipped plant material was oven dried and weight was recorded. Data on water used, nitrogen content and carbohydrate content were also recorded.

Field Experiment I

Description of study area

The Nephi Dryland Research Station is situated about 12 km south of Nephi, Utah, in Juab County at an elevation of 1615 m. Mean annual precipitation is 320 mm. Mean annual air temperature ranges from 9 C to 11 C and the average frost free season is 110 days. The monthly precipitation data for the fall growing season are given in Table 3. A drought index of Nephi area prepared by the Soils and Biometerology Department of Utah State University gives a 20 percent probability of occurrence of the wet or above average precipitation pattern such as in the fall of 1980.

Soil at the Nephi station is silt loam, very deep and well drained. This soil was derived mainly from shale, limestone and sandstone parent material. In a typical profile the surface layer is a brown silt loam about 20 cm thick. The subsoil is a brown, silty clay about 35 cm thick. The substratum is light brown, silt loam or silty clay to depths of 150 cm or more. The area lies in the Xerolic-Hapalargids-Xerolic Calciorthids soil association.

The original vegetation in the surrounding area consisted of big sagebrush, scattered juniper, bluebunch wheatgrass and Indian

Table 3. Average monthly precipitation recorded at Nephi Field Station showing current 1971-1981 years and the 78-year average (mm).

Years	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1971	26	33	6	53	36	8	19	37	18	53	24	44	357
1972	3	13	0	22	11	19	5	27	28	96	43	31	298
1973	38	23	52	37	30	22	22	12	7	10	41	24	318
1974	36	9	10	40	4	1	12	11	0	36	6	4	169
1975	24	27	44	10	49	8	5	1	0	25	28	21	243
1976	10	14	14	19	4	7	20	10	23	0	9	2	132
1977	13	18	34	2	56	6	36	29	14	3	7	27	245
1978	70	43	70	68	25	0	0	16	38	9	72	14	425
1979	33	26	52	22	27	0	7	27	1	43	24	21	283
1980	63	81	63	23	64	5	4	7	42	43	32	20	447
1981	13	18	52	32	61	5	16	9	-	-	-	-	-
78/year Average	30	31	36	34	34	17	21	24	25	31	27	26	336

Personal communication from Associate Professor Gordon Van Epps, Snow Field Station, Ephraim, Utah.

ricegrass. For over the last 100 years dryland cereals have replaced the original plant cover. For the last 8-15 years the field station has been planted to various salt desert shrubs in pure and mixed stands with crested wheatgrass. A field of eight-year old fourwing saltbush plants is presently managed for seed production. Crested wheatgrass pastures are harvested each year after they have gone dormant.

Establishing field plots

In the first week of September 1980, plantings of crested wheatgrass and fourwing saltbush plants were selected to receive the irrigation and nitrogen fertilization treatments (Figures 3 and 4). Each plot consisted of a meter^2 area for the purpose of application of treatments. A one-meter border on each side of the plots was left untreated to reduce the boundary effect.

During the study period, half of the plots were surface irrigated three times at a rate of 5 mm at 20 day intervals, while the remaining plots were maintained under natural conditions. This provided a total of 15 mm more water in irrigated plots than the plots under natural conditions. Precipitation received during the study period was 85 mm, which was an above normal year (Table 3). In this wet year, a differential of 15 mm irrigation was inadequate to produce significant results. In addition irrigation distribution in the plots was not uniform. Therefore, the results of irrigation treatments in the field experiment are not included.

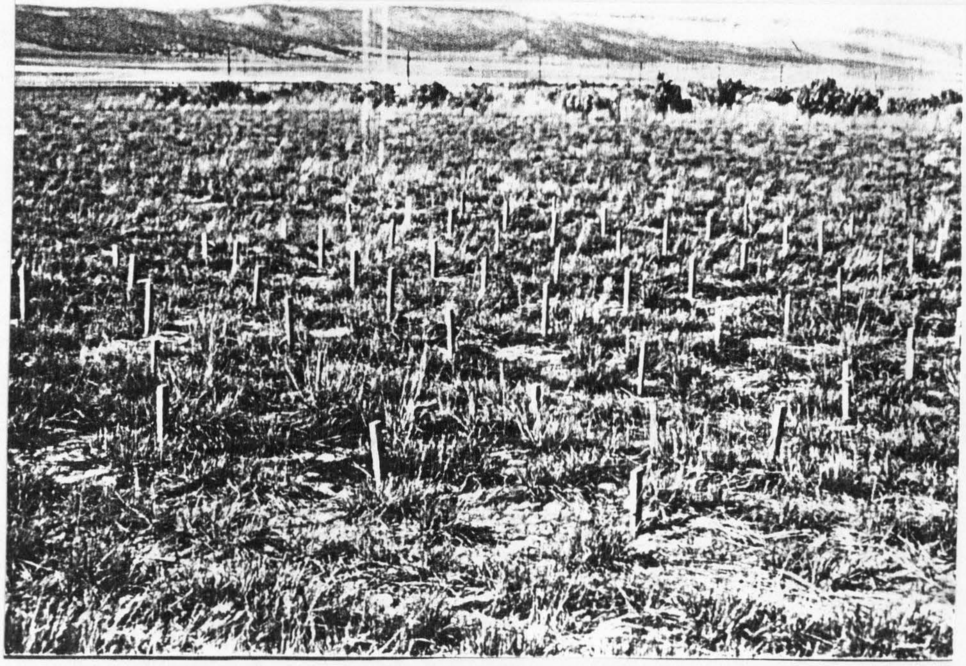

Figure 3. Crested wheatgrass plots at Nephi Dryland Research Station subjected to two irrigation and three N fertilizer levels.

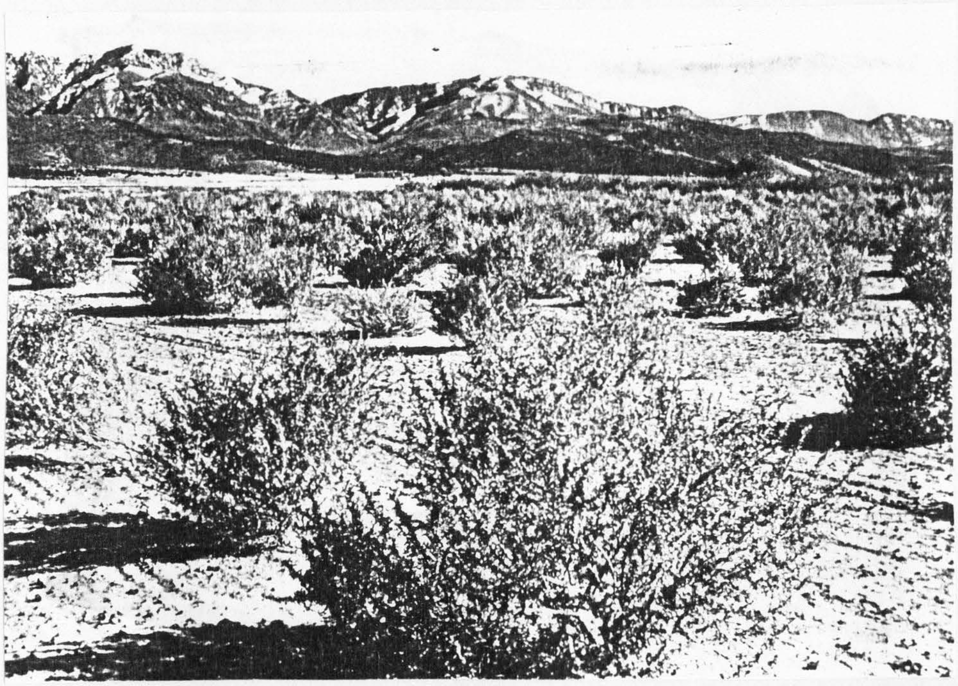

Figure 4. Fourwing saltbush plants at Nephi Dryland Research Station subjected to two irrigation and three N fertilizer levels.

Nitrogen fertilization

In various range fertilization studies, McCormick and Workman (1975) suggested that nitrogen application at a rate of 50 kg N/ha is economical in foothill range areas of the Great Basin. Therefore, three nitrogen treatments (0, 50 and 100 kg N/ha) provided extreme and optimum nitrogen treatments. For the purpose of determining the area to receive N fertilizer each fourwing saltbush plant was considered to occupy a square-meter plot, which was generally less or equal to the surface area covered by the plant canopy.

Nitrogen fertilizer was applied in granular form on the surface of randomly selected plots on September 2, 1980. No additional fertilizer was applied during the 60-day study period.

Measurement of productivity

In the first week of September, 1980, crested wheatgrass plots were clipped to 2 cm stubble height to remove the residual from spring and summer growth. The regrowth yield was clipped on November 1, 1980. This 60-day study period approximated the fall regrowth period prevailing in the Intermountain region.

Fall regrowth for fourwing saltbush was determined by selecting four twigs of the same size and length (10 cm each) from each plant. Two twigs of 10 cm each were clipped at the beginning of the experiment while the remaining two were tagged at 10 cm length point. The second two twigs were clipped at the tag point after the 60 day study period. The difference between the first two twigs clipped at the beginning and the second two twigs clipped at the termination of the study provided an estimate of relative incremental yield during the fall regrowth period. This technique reduced the damage to the plants as they are maintained for seed production.

Careful selection and measurement of the twigs reduced the variability. The standard deviation values for 0, 50 and 100 Kg N/ha treatments were 0.5, 0.6 and 0.4 respectively, which represented sufficient sampling accuracy.

On June 4, 1981, the same crested wheatgrass plots were clipped to the ground level for determination of spring regrowth. All the new twigs from one fourth part of each plant of fourwing saltbush were clipped to calculate the spring regrowth.

Field Experiment II

The 1980 fall growing season happened to be a wet season, an event that has about a 20 percent probability of occurrence in this region. Therefore, results of the experiment did not have wide applicability for the semi arid rangelands of the western United States. However, both the growth chamber experiment as well as the field experiment conducted during fall 1980 and spring 1981 showed that a significant increase in the dry matter yield of crested wheatgrass and fourwing saltbush was possible with the application of nitrogen fertilizer. Such results suggested a need to determine the effects of nitrogen fertilization under dry, medium and wet fall growing seasons along with possible relationships between soil nitrogen penetration and the extent of crested wheatgrass and fourwing saltbush root systems under field conditions. Therefore, another experiment was laid out at Nephi during the late summer of 1981, where crested wheatgrass and fourwing saltbush plants were subjected to three soil moisture regimes (dry, medium and wet) and three nitrogen fertilizer levels (0, 50 and 100 kg N/ha). The data from both field experiments were used to examine hypothesis number three stated earlier.

Layout of experiment

During the summer of 1981 thirty six m^2 plots of crested wheatgrass and 36 plants of fourwing saltbush were selected at Nephi. For the purpose of determining the area to receive irrigation and fertilizer, each fourwing saltbush plant was considered to occupy a m^2 plot which was generally equal to the amount covered by a plant. Crested wheatgrass, on average consisted of four plants per meter square plot. A meter square border on each side of a plot was left untreated to reduce the boundary effect.

Nitrogen fertilization and irrigation schedule

Nitrogen fertilizer (0, 50 and 100 kg N/ha) was applied to randomly selected plots at the beginning of the experiments. The nitrogen fertilization procedures followed were the same as described for field experiment I.

Three soil moisture regimes of dry, medium and wet were maintained by hand-watering the plots at a 15-day interval. Dry, medium and wet soil moisture regimes were selected from the 78-year rainfall data recorded at Nephi Dryland Research Station (Table 3). The medium and wet plots received 45 and 85 mm of water respectively in addition to natural rainfall received during the 60-day study period. The medium irrigation regime was based on the average rainfall received in this area while the wet regime represents above normal years. Forty five to

63 mm have 50 percent probability of occurrence while 85 mm and above has 20 percent probability of occurrence. Total rainfall received during the study period was 18 mm which has 30 percent probability of occurrence. Soil water content of the plots at depths of 5, 10, 20, 30, 40, 50, and 70 was also recorded at the beginning and end of the experiment by using soil cores and gravimetric methods (Hanks and Ashcroft 1980). Initial soil water content was determined after one hour of the first irrigation. However, the second soil sampling was done at the end of the 60-day study period. This soil water content measurement schedule provided data on the soil water content at the beginning and end of the study period.

Measurement of productivity

At the end of the 60-day study period, crested wheatgrass was clipped to 2 cm stubble height. Clipping procedures for fourwing saltbush were same as described for spring regrowth during field experiment I.

Root biomass

Three plants each of crested wheatgrass and fourwing saltbush were selected at Nephi to determine a relationship among soil water, soil nitrogen percolation and effective root system at different incremental depths, the below-ground portion of each plant was excavated while the remaining half was left intact so that plants could be used for seed production studies. Root sampling methods were same as used by Sturges and Trlica (1978).

Sampling proceeded laterally outward from the stem and downward into the soil to encompass all root matter lying within each 5 cm incremental depth up to 90 cm soil depth. Roots from each incremental depth were placed in a plastic bag separately. Root weight for each incremental depth was recorded after oven drying the root at 60 C for 24 hours. This value was multiplied by two to calculate total root weight for each plant at each incremental depth. Calculated root weights were then summed over depth to estimate total root system weight. The root system pattern of fourwing saltbush was further studied by excavating plant roots from adjacent plants under biomass studies at the Nephi Dryland Research Station. Tap roots of fourwing saltbush were not clipped and are not included in total root biomass.

Soil nitrogen sampling

At the end of the 60-day study period, soil samples from each plot of the 1981 field experiment were collected at 5, 10, 20, 30 and 40 cm soil depth. The soil auger was driven under the plant canopy. The 15 cm distance of the sampling point from plant base was kept constant to avoid the varying effect of plant canopy on nitrogen/water percolation in the soil. The soil samples thus obtained were analyzed for NO_3-N content.

Laboratory Analysis

Sample preparation

Samples of roots, stems and leaves of crested wheatgrass and fourwing saltbush were collected separately at the beginning and at the end of the field study as well as in the growth chamber experiment. Plant material of all replications was combined for each treatment in the growth chamber study as the dry plant tissue for each replication was not in sufficient quantity for both total nitrogen and total nonstructural carbohydrate (TNC) analysis. The samples were dried at 60 C for 24 hours, weighed, and ground through a 40" mesh screen.

Nitrogen analysis

Nitrogen content in plants was determined by using a micro-Kjeldahl apparatus and techniques of Harris (1970) as modified by the Soil Analysis Laboratory, Soil Science Department, Utah State University. Three hundred and sixty soil samples collected from field experiment number two were analyzed to determine soil nitrate. The methods and procedures were the same as described by Richards (1954) and modified by the Soil Science Department, Utah State University.

Total nonstructural carbohydrate analysis

A modified Weinmann method described by Smith (1969) was used to determine the total nonstructural carbohydrates (TNC) in plant tissue. One hundred mg of amylogucosidae enzyme was used for every 100 mg plant dry tissue instead of the takadiastase enzyme. Reducing power was measured by the Shaeffer-Somogyi copperiodometric titration method described by Heinze and Murneek (1940).

Design of Experiments

Statistical design for growth chamber experiment

Three growth chambers, each two square meters in shelf capacity were used to conduct the experiment. The experimental design was a factorial split-plot with the following specifications:

1. Two species: crested wheatgrass and fourwing saltbush
2. Two water stress regimes: field capacity and wilting point percentage
3. Three temperature regimes: 27/7 C day/night
   19/7 C day/night
   11/7 C day/night
4. Three N fertilization levels: control, 50, and 100 kg N/ha
5. Four replications:

Statistical design for the field experiment I

The experiment consisted of laying out 15, one square-meter plots of crested wheatgrass and selecting 15 plants of fourwing saltbush. A randomized complete block design was used to apply the following treatments during first week of September 1980.

1. Two species: crested wheatgrass and fourwing saltbush.
2. Three N fertilizer rates: control, 50 and 100 kg/ha.
3. Five replications:

Statistical design for field experiment II

On July 14, 1981, 36 one-square meter plots of crested wheatgrass and 36 plants of fourwing saltbush were delineated at Nephi Dryland Research Station. A three-way factorial design was used to apply the following treatments during the 60-day study period:

1. Two species: crested wheatgrass and fourwing saltbush.
2. Three N fertilizer rates: control, 50 and 100 kg/ha.
3. Three irrigation regimes: dry, medium and wet.
4. Four replications:

Analysis of Data

A factorial analysis-of-variance computer program was used to analyze the data on plant productivity. Data for water use efficiency, nitrogen content and carbohydrate reserves were analyzed by using Stepwise Multiple Regression programs described by Hurst (1977). Statistical significance was determined for each treatment by means of a standard F test. A Multiple Range Test for multiple comparisons (Ott 1977) was applied to determine differences among treatment means.

Crested wheatgrass and fourwing saltbush were treated as individual experiments for the analysis of data obtained during the two field experiments.

RESULTS

Growth Chamber Experiment

Water use efficiency of plants

Water use efficiency of plants is defined as the amount of dry matter produced per unit of water lost. Effect of N fertilization on the water use efficiency of crested wheatgrass and fourwing saltbush was determined by recording transpiration at 48 hour intervals during a 60 day growth chamber experiment. In addition, the ratio between plant biomass and total transpiration was determined by clipping plants at the end of the study (Table 4).

Crested wheatgrass and fourwing saltbush showed variable response in water use efficiency due to species, temperature, water stress and nitrogen treatments (Figures 5 and 6). Among the two way interactions, only species x water stress, species x temperature and fertilizer x water stress were significant. All other interactions were non-significant at the 0.05 level (Table 5).

Crested wheatgrass was more efficient in water use than fourwing saltbush when averaged across all treatments (Table 5). Crested wheatgrass plants kept in the high temperature (27/7C) regime were more efficient than the plants at low temperature (11/7C). However, no significant difference in water use efficiency was noticed when plants at the medium temperature (19/7C) regime were compared either with high temperature or low temperature treatments. Fourwing saltbush did not show a difference in water use efficiency between

Table 4. Transpiration, dry matter yield and water use efficiency biomass (gm/1000/gms transp.) of crested wheatgrass and fourwing saltbush plants maintained for 60 days in growth chambers under three temperature regimes, two water stress regimes and three N fertilizer levels. Values are means of four replications.

Species	Observation	27/7c day/night Nitrogen Kg/ha 0	50	100	19/7c day/night Nitrogen Kg/ha 0	50	100	11/7c day/night Nitrogen Kg/ha 0	50	100	
Crested Wheatgrass	PLANTS MAINTAINED AT FIELD CAPACITY REGIME										
	Transpiration	1135	2423	2500	457	1231	1582	300	999	1081	(grams)
	Dry matter	1.5	3.7	4.0	0.6	1.8	2.5	0.4	1.4	1.6	(grams)
	PLANTS MAINTAINED AT WILTING POINT REGIME										
	Transpiration	351	689	709	294	403	584	217	345	392	(grams)
	Dry matter	0.5	1.1	1.2	0.4	0.6	0.9	0.3	0.5	0.6	(grams)
Fourwing Saltbush	PLANTS MAINTAINED AT FIELD CAPACITY REGIME										
	Transpiration	1117	1965	4306	843	1125	1658	261	643	680	(grams)
	Dry matter	1.4	2.7	6.1	1.0	1.5	2.3	0.3	0.8	0.9	(grams)
	Water use efficiency	1.2	1.3	1.4	1.1	1.3	1.4	1.1	1.2	1.3	
	PLANTS MAINTAINED AT WILTING POINT REGIME										
	Transpiration	437	542	925	301	433	906	79	299	427	(grams)
	Dry matter	0.6	0.8	1.5	0.4	0.6	1.3	0.1	0.4	0.6	(grams)
	Water use efficiency	1.4	1.4	1.6	1.3	1.4	1.4	1.2	1.3	1.4	

TEMPERATURE REGIMES

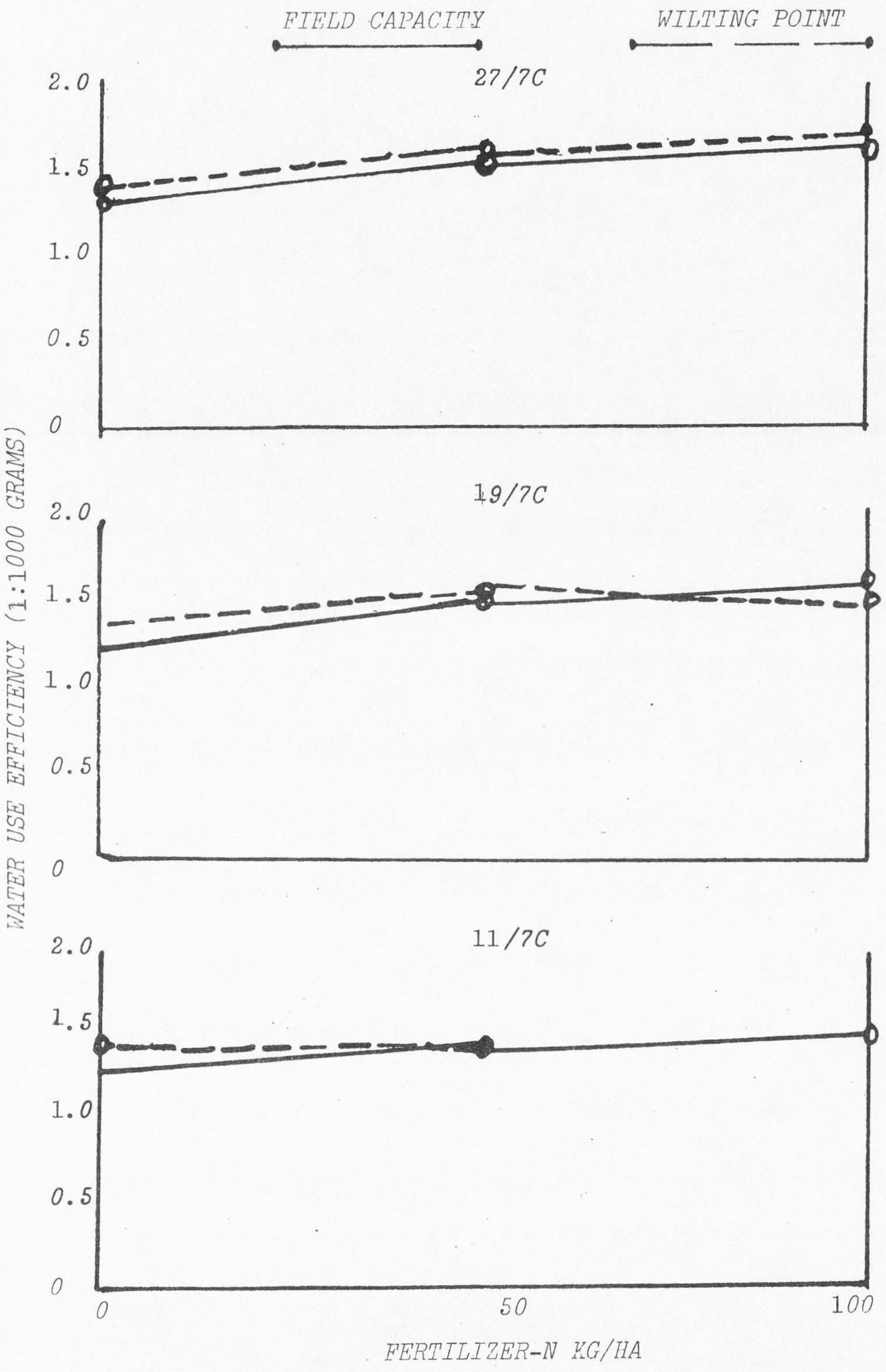

Figure 5. Average water use efficiency of crested wheatgrass grown in growth chambers and subjected to three temperature regimes, two water stress regimes and three N fertilizer levels. Values are means of four replications.

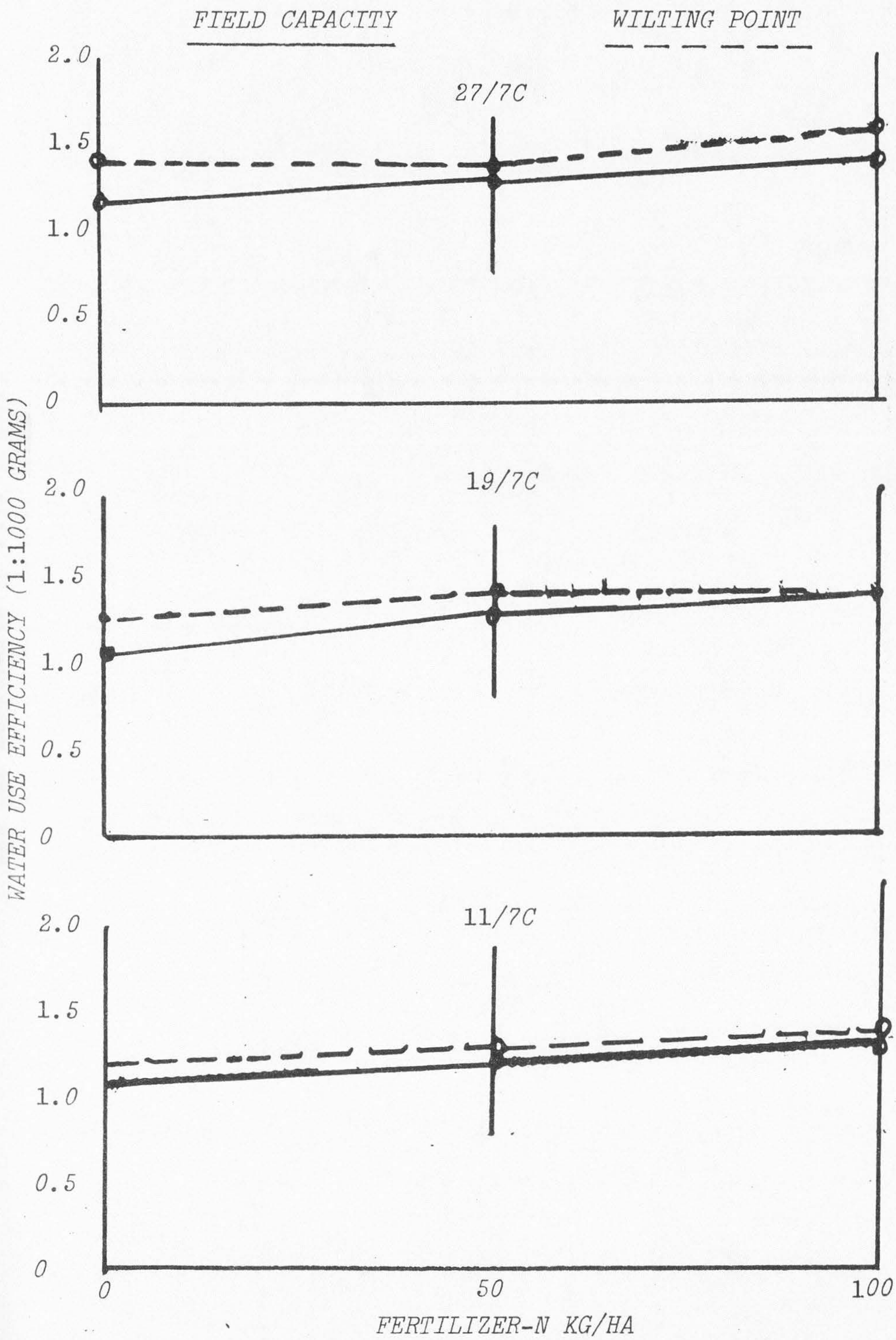

Figure 6. Average water use efficiency of fourwing saltbush grown in growth chamber and subjected to three temperature regimes, two water stress regimes and three N fertilizer levels. Values are means of four replications.

Table 5. Treatment mean comparisons of water use efficiency for crested wheatgrass and fourwing saltbush maintained for 60 days in a growth chamber under three temperature regimes, two water stress regimes and three N fertilizer levels. (See Table 14 in Appendix for Analysis of Variance).

Treatment		Mean*
Species		
4-wing saltbush		1.34 a
crested wheatgrass		1.46 b
Temperature		
11/7 C		1.35 a
19/7 C		1.39 ab
27/7 C		1.46 b
Water Stress		
FC		1.36 a
WP		1.44 b
Fertilizer N Kg/ha		
0		1.36 a
50		1.44 b
100		1.58 c
Species X Water Stress		
4-wing	FC	1.30 a
4-wing	WP	1.41 b
cwg	FC	1.49 c
cwg	WP	1.52 c
Species X Temperature		
4-wing	11/7 C	1.28 a
4-wing	19/7 C	1.34 a
4-wing	27/7 C	1.41 b
cwg	11/7 C	1.43 b
cwg	19/7 C	1.45 bc
cwg	27/7 C	1.52 c
N Fertilizer X Water Stress		
control	FC	1.26 a
control	WP	1.35 b
50	FC	1.38 bc
50	WP	1.45 c
100	FC	1.46 cd
100	WP	1.53 d

* Treatment means followed by different letters are significant at 0.05 level. All other interactions were non significant at 0.05 level.

11/7 and 19/7C temperature regime. However, it was significantly less at 27/7C. Water stress had a positive influence on water use efficiency of fourwing saltbush. Crested wheatgrass did not respond to water stress treatments (Table 5).

Nitrogen fertilizer significantly increased water use efficiency of plants. Efficiency increased as the amount of nitrogen was increased from zero to 100 kg N/ha. Nitrogen addition (100 kg N/ha) under high water stress was not any more effective in increasing water use efficiency than growing plants at field capacity with the same fertilizer level. Fifty kg N/ha fertilizer under high water stress (-15 bars) was equally efficient to 50 or 100 kg N/ha application under field capacity, soil moisture regime. Moderate amounts of nitrogen fertilizer (50 kg N/ha) applied to plants at field capacity increased water use efficiency equal to unfertilized plants maintained at wilting point. Unfertilized plants at wilting point were more efficient than the plants under field capacity without fertilizer (Table 5).

It is therefore inferred that nitrogen fertilization increases the water use efficiency of plants. The results further suggest that crested wheatgrass was more efficient in water use under low temperature and high water stress than fourwing saltbush when averaged over all treatments.

Plant biomass

Under controlled environmental conditions, the production of crested wheatgrass and fourwing saltbush increased as the temperature, soil moisture and the amount of nitrogen was increased. However, the magnitude of increase in dry matter yield varied from treatment to treatment (Figures 7 and 8).

Temperature was an important variable controlling plant growth followed by availability of nitrogen and soil moisture. The dry matter yield of crested wheatgrass and fourwing saltbush was differentially affected by temperature, water stress and nitrogen treatments. The only nonsignificant difference in dry matter yield was noticed between two species when averaged across all treatments. The two, three and four-way interactions were variously affected due to highly significant effects of major treatments on the dry matter yield of both species. Certain interactions relevant to the application of the results to fall range management are discussed below. Many other interactions could be mentioned but would not be relevant to the hypotheses being tested.

Yields tended to increase with N fertilizer application. Plant yields at each of the three nitrogen levels were significantly different from each other when averaged across all treatments. The increase of yield with 50 kg N/ha was double the amount for plants grown without fertilizer. With the application of 100 kg N/ha, dry matter increased by three fold over the non application treatments (Table 6).

Unfertilized plants of crested wheatgrass maintained at wilting point regime did not show a difference in dry matter yield due to different temperature treatments. Increasing the soil moisture to field capacity under low temperature regime (11/7C) also gave a similar yield. Dry matter yield of unfertilized crested wheatgrass under field

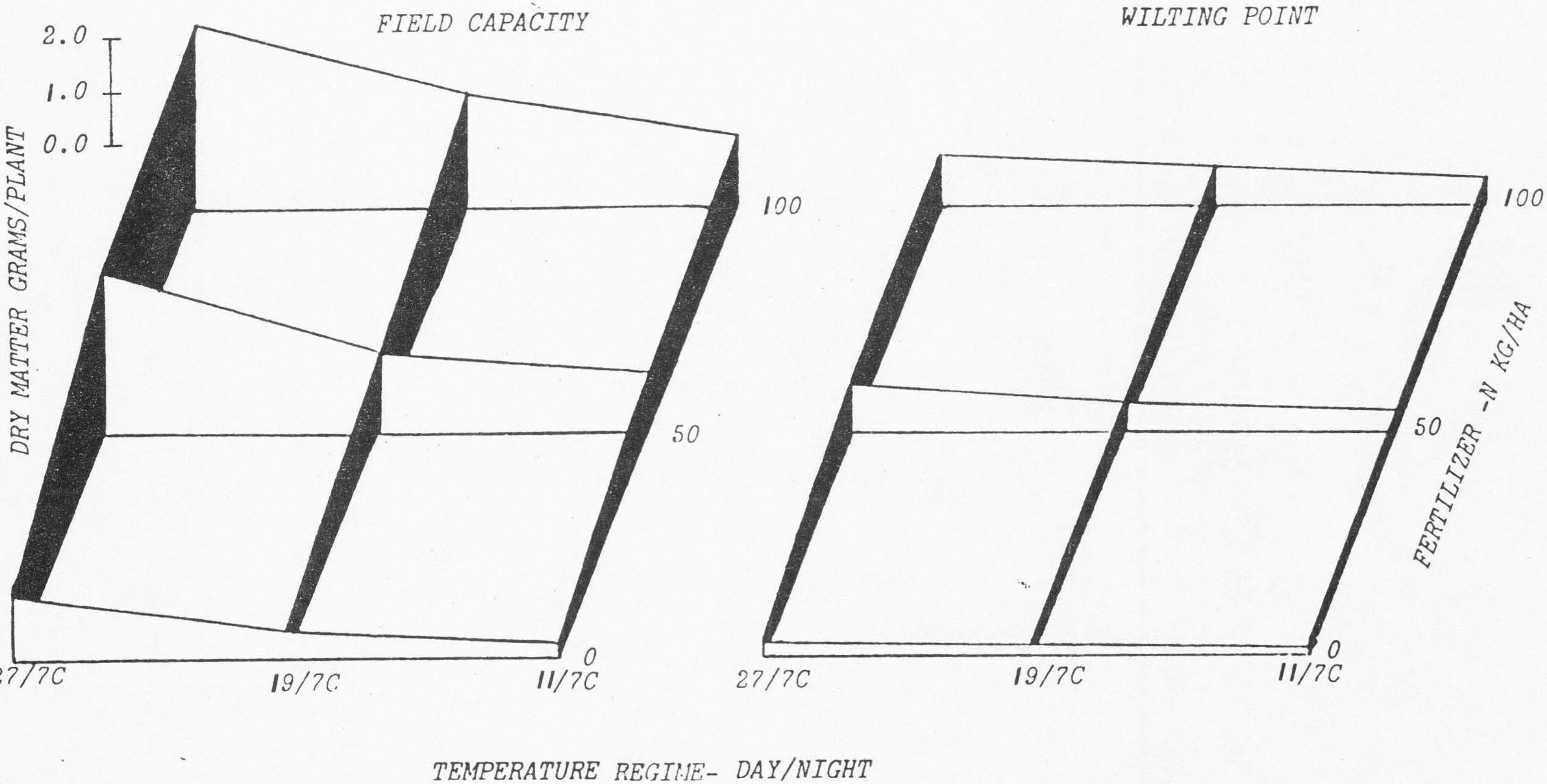

Figure 7. Average dry matter yield of crested wheatgrass grown in growth chambers and subjected to three temperature regimes, two waterstress regimes and three N fertilizer levels. Values are means of four replications.

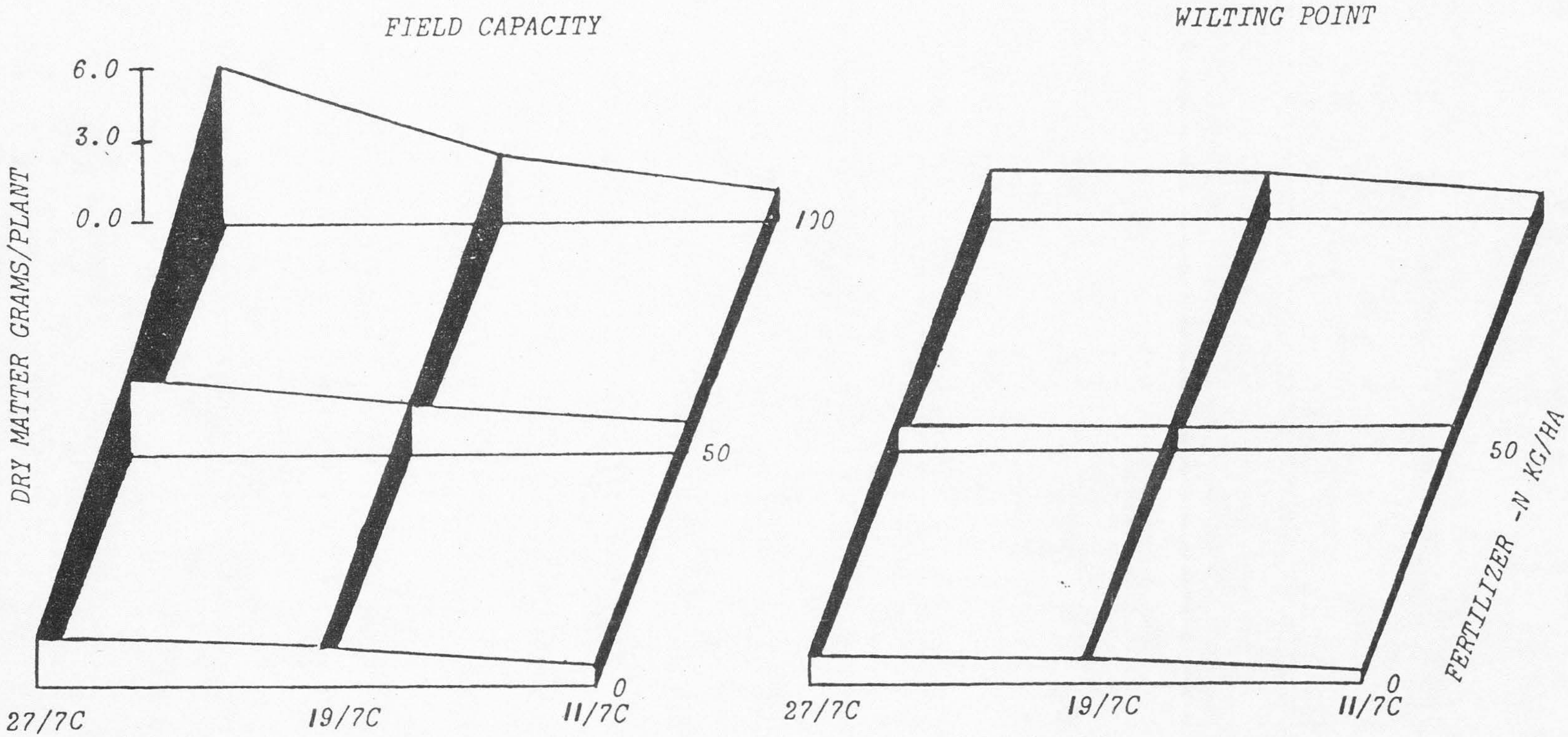

Figure 8. Average dry matter yield of fourwing saltbush grown in growth chambers and subjected to three temperature regimes, two water stress regimes and three N fertilizer levels. Values are means of four replications.

Table 6. Treatment mean comparisons of dry matter yield (gram/plant) of crested wheatgrass and fourwing saltbush maintained for 60 days under three temperature regimes, two water stress regimes and three N fertilizer levels. (See Table 15 in Appendix for Analysis of Variance).

Treatment		Mean*	Treatment		Mean*
Species			Temperature X Water Stress		
4-wing saltbush		N.S.	27/7 C	FC	3.2 a
crested wheatgrass		N.S.	19/7 C	FC	1.5 b
			27/7 C	WP	0.9 c
Temperature			11/7 C	FC	0.8 c
			19/7 C	WP	0.6 c
27/7 C		2.1 a	11/7 C	WP	0.5 c
19/7 C		1.1 b			
11/7 C		0.6 c	Temperature X N Fertilizer		
Water Stress Regimes			27/7 C	100	3.2 a
			27/7 C	50	2.0 b
FC		1.8 a	19/7 C	100	1.7 b
WP		0.7 b	19/7 C	50	1.1 c
			27/7 C	0	1.0 c
N Fertilizer (Kg/ha)			11/7 C	50	0.9 cd
			11/7 C	100	0.8 cd
100		1.9 a	11/7 C	0	0.5 d
50		1.3 b	19/7 C	0	0.9 cd
0		0.6 c	N Fertilizer X Water Stress		
Species X Temperature			100	FC	2.8 a
			50	FC	2.0 b
4-wing	27/7 C	2.2 a	100	WP	1.0 c
cwg	27/7 C	2.0 a	0	FC	0.8 c
4-wing	19/7 C	1.1 b	50	WP	0.7 cd
cwg	19/7 C	1.1 b	0	WP	0.4 d
cwg	11/7 C	0.7 bc			
4-wing	11/7 C	0.5 c	Species X N Fertilizer		
Species X Water Stress			4-wing	100	2.0 a
			cwg	100	1.7 ab
cwg	FC	1.9 a	cwg	50	1.5 b
4-wing	FC	1.8 a	4-wing	50	1.5 b
4-wing	WP	0.7 b	4-wing	0	0.6 c
cwg	WP	0.6 b	cwg	0	0.6 c

* Treatment means followed by different letters are significant at 0.05 level

Table 6. Continued

Treatment			Mean*	Treatment			Mean*
S x T x W				S x F x W			
4-wing	27/7 C	FC	3.5 a	4-wing	100	FC	2.9 a
cwg	27/7 C	FC	3.1 a	cwg	100	FC	2.7 a
cwg	19/7 C	FC	1.6 b	cwg	50	FC	2.3 b
4-wing	19/7 C	FC	1.5 b	4-wing	50	FC	1.6 c
cwg	11/7 C	FC	1.1 c	4-wing	100	WP	1.1 d
4-wing	27/7 C	WP	1.0 c	4-wing	0	FC	0.9 de
cwg	27/7 C	WP	0.9 c	cwg	100	WP	0.9 de
4-wing	19/7 C	WP	0.6 d	cwg	0	FC	0.8 de
cwg	19/7 C	WP	0.6 d	cwg	50	WP	0.7 e
4-wing	11/7	FC	0.5 d	4-wing	50	WP	0.7 e
4-wing	11/7	WP	0.5 d	cwg	0	WP	0.3 f
cwg	11/7	WP	0.4 d	4-wing	0	WP	0.3 f
S x T x F				T x F x W			
4-wing	27/7 C	100	2.8 a	27/7 C	100	FC	5.1 a
cwg	27/7 C	100	2.6 a	27/7 C	50	FC	3.2 b
cwg	27/7 C	50	2.4 b	19/7 C	100	FC	2.4 c
4-wing	27/7 C	50	1.8 c	19/7 C	50	FC	1.7 d
4-wing	19/7 C	100	1.8 c	27/7 C	0	FC	1.6 d
cwg	19/7 C	100	1.7 c	27/7 C	100	WP	1.4 de
cwg	19/7 C	50	1.2 d	19/7 C	100	WP	1.1 ef
4-wing	19/7 C	50	1.1 e	11/7 C	50	FC	1.1 ef
cwg	11/7 C	100	1.1 de	11/7 C	100	FC	1.0 f
4-wing	27/7 C	0	1.1 de	27/7 C	50	WP	0.9 fg
cwg	27/7 C	0	1.0 de	11/7 C	100	WP	0.8 fg
cwg	11/7 C	50	0.9 def	19/7 C	50	WP	0.6 gh
4-wing	11/7 C	50	0.8 efg	19/7 C	0	FC	0.6 gh
4-wing	19/7 C	0	0.6 fg	11/7 C	50	WP	0.6 gh
4-wing	11/7 C	100	0.5 gh	27/7 C	0	WP	0.6 gh
cwg	19/7 C	0	0.5 gh	19/7 C	0	WP	0.4 hi
cwg	11/7 C	0	0.3 h	11/7 C	0	FC	0.4 hi
4-wing	11/7 C	0	0.2 h	11/7 C	0	WP	0.2 i

* Treatment means followed by different letters are significant at 0.05 level.

Table 6. Continued

Treatment	Mean *
S x T x F x W	
4-wing 27/7c 100 FC	6.1 a
cwg 27/7c 100 FC	4.0 b
cwg 27/7c 50 FC	3.7 c
4-wing 27/7c 50 FC	2.7 d
cwg 19/7c 100 FC	2.5 de
4-wing 19/7c 100 FC	2.3 e
cwg 19/7c 50 FC	1.8 f
4-wing 27/7c 0 FC	1.6 fg
4-wing 27/7c 50 WP	1.6 fg
cwg 11/7c 100 FC	1.6 fg
4-wing 27/7c 100 WP	1.5 gh
4-wing 19/7c 50 FC	1.5 gh
cwg 27/7c 0 FC	1.5 gh
cwg 11/7c 50 FC	1.4 gh
4-wing 19/7c 100 WP	1.3 h
cwg 27/7c 100 WP	1.2 h
cwg 27/7c 50 WP	1.0 i
cwg 19/7c 100 WP	0.9 i
4-wing 19/7c 50 WP	0.8 ij
4-wing 11/7c 50 FC	0.8 ij
4-wing 11/7c 50 WP	0.8 ij
4-wing 19/7c 0 FC	0.7 jk
cwg 11/7c 50 WP	0.7 jk
cwg 19/7c 50 WP	0.6 jk
cwg 19/7c 0 FC	0.6 jk
4-wing 27/7c 0 WP	0.6 jk
cwg 11/7c 100 WP	0.5 kl
4-wing 11/7c 100 WP	0.5 kl
cwg 27/7c 0 WP	0.5 kl
4-wing 11/7c 100 FC	0.5 kl
cwg 11/7c 100 WP	0.5 kl
cwg 11/7c 0 FC	0.4 kl
4-wing 19/7c 0 WP	0.4 kl
cwg 19/7c 0 WP	0.4 kl
4-wing 11/7c 0 FC	0.3 l
cwg 11/7c 0 WP	0.3 l
4-wing 11/7c 0 WP	0.3 l

* Treatment means followed by different small letters are significant at 0.05 level.

capacity soil moisture regime at medium temperature (19/7C) was significantly increased when compared to plants under low temperature and high water stress.

Under the wilting point soil moisture regime, a moderate amount of nitrogen (50 kg/ha) application at 11/7 and 19/7C temperature regime or 100 kg N/ha level at 11/7C temperature produced an equal amount of dry matter in crested wheatgrass which was significantly more than the yield obtained from unfertilized plants maintained under low temperature and high water stress.

A moderate amount of nitrogen (50 kg/ha) at the 27/7C temperature regime plus heavy nitrogen fertilizer (100 kg N/ha) had equal effect on production of crested wheatgrass maintained under the wilting point soil moisture regime. However, the yields were greater than from those treatments mentioned in the preceding paragraph.

Dry matter yield of crested wheatgrass under the wilting point and 27/7C temperature regime was further increased as the amount of nitrogen applied was increased to 100 kg N/ha level. The result was equal to the biomass obtained from unfertilized crested wheatgrass maintained at field capacity and 27/7C temperature or moderately fertilized (50 kg N/ha) plants under low temperature and field capacity.

With 100 kg N/ha fertilizer crested wheatgrass production under low temperature and field capacity was the same when compared either with moderately fertilized plants under medium temperature (19/7C) and field capacity treatments or unfertilized crested wheatgrass maintained at field capacity and the high temperature (27/7C) regime.

Under the field capacity soil moisture regime crested wheatgrass biomass was highest with 100 kg N/ha at 27/7C followed by 50 kg N/ha application to plants at 27/7C or 100 kg N/ha fertilization at 19/7C temperature regime.

Under the low temperature regime (11/7C), a heavy amount of nitrogen application (100 kg N/ha) and water stress treatments did not change the dry matter yield of fourwing saltbush. No difference in dry matter yield of unfertilized fourwing saltbush at medium temperature and field capacity soil moisture regime was found when compared with fourwing saltbush maintained under low temperature and fertilized at 50 kg N/ha level. The effect of water stress in this case was non-significant. The yield with 50 kg N/ha application at medium temperature and high water stress was also the same (Table 6).

Plant grown in the wilting point soil moisture regime with a heavy nitrogen (100 kg N/ha) rate at 19/7 or 27/7C temperature produced the same amount of dry matter as obtained from plants grown under field capacity with a fertilizer rate of 50 kg N/ha and the medium temperature regime.

Unfertilized fourwing saltbush maintained at field capacity and grown in a high temperature (27/7C) regime gave as much dry matter as obtained from plants given 100 kg N/ha fertilization in wilting point and high temperature treatments. Under a field capacity soil moisture regime, production of fourwing saltbush was highest at 27/7C temperature with 100 kg N/ha. Yields were less under a treatment of a moderate amount of nitrogen (50 kg N/ha) application at 27/7C. Plant biomass was further reduced when plants were grown at 19/7C with 100 kg N/ha application (Table 6).

Nitrogen percent in plants

At the end of the 60-day growth chamber experiment, large differences in nitrogen percent of leaves, stems and roots of crested wheatgrass and fourwing saltbush were evident (Table 7). The plant response to treatments varied from one storage organ to the other. In general leaves of crested wheatgrass and fourwing saltbush contained the same percent of nitrogen. However, stems and roots of fourwing saltbush contained significantly higher nitrogen than stems and roots of crested wheatgrass respectively (Figures 9 and 10). This might be due to physiological differences between grasses and shrubs.

Leaf N content of crested wheatgrass was higher at the 11/7C temperature regime than under 19/7 or 27/7C temperature regimes. Nitrogen percent of crested wheatgrass stems was significantly different between the 19/7 and the 27/7 temperature regime. No difference in the N content of stems at 19/7C was observed when compared with plants at 11/7 or 27/7C temperature regime. Roots of crested wheatgrass did not differentially respond to temperature treatments (Table 8).

Nitrogen percent in leaves of fourwing saltbush was significantly higher at 11/7C temperature than plants kept under 19/7 or 27/7C temperature regime. Stems of fourwing saltbush did not respond to temperature treatments. Roots had more N at 11/7 when compared to plants at 19/7C but these were equal to 27/7C temperature regime (Table 8).

Leaves, stems and roots of fourwing saltbush had an equal response to the 50 or 100 kg N/ha level. However, each plant part contained significantly more nitrogen than the respective organs of unfertilized plants. In crested wheatgrass a moderate amount of nitrogen fertilizer

Table 7. Nitrogen percent in leaves, stems and roots of crested wheatgrass and fourwing saltbush maintained for 60 days under three temperature regimes, two water stress regimes and three N fertilizer levels. The values are means of four replications.

Obs		Temperature Regimes								
		27/7c day/night Nitrogen Kg/ha			19/7 c day/night Nitrogen Kg/ha			11/7c day/night Nitrogen Kg/ha		
		0	50	100	0	50	100	0	50	100
CRESTED WHEATGRASS		PLANTS MAINTAINED NEAR FIELD CAPACITY								
	Leaves	0.77	0.87	1.45	1.38	1.44	1.88	1.77	1.92	2.70
	Stems	0.49	0.54	0.65	0.68	0.72	1.25	0.72	0.91	1.28
	Roots	0.55	0.59	0.80	0.64	0.68	0.85	0.67	0.72	0.98
		PLANTS MAINTAINED NEAR WILTING POINT								
	Leaves	1.18	1.39	2.04	1.24	1.52	2.36	1.36	1.74	2.44
	Stems	0.44	0.62	0.72	0.46	0.73	1.18	0.57	1.02	1.26
	Roots	0.77	0.73	0.86	0.71	0.85	0.87	0.77	0.96	1.04
FOURWING SALTBUSH		PLANTS MAINTAINED NEAR WILTING POINT								
	Leaves	1.11	1.78	2.26	0.89	1.64	2.24	1.44	2.10	2.29
	Stems	0.82	1.12	1.36	0.79	1.09	1.22	0.79	1.13	1.42
	Roots	1.02	1.07	1.76	0.90	1.26	1.26	1.18	1.60	1.66

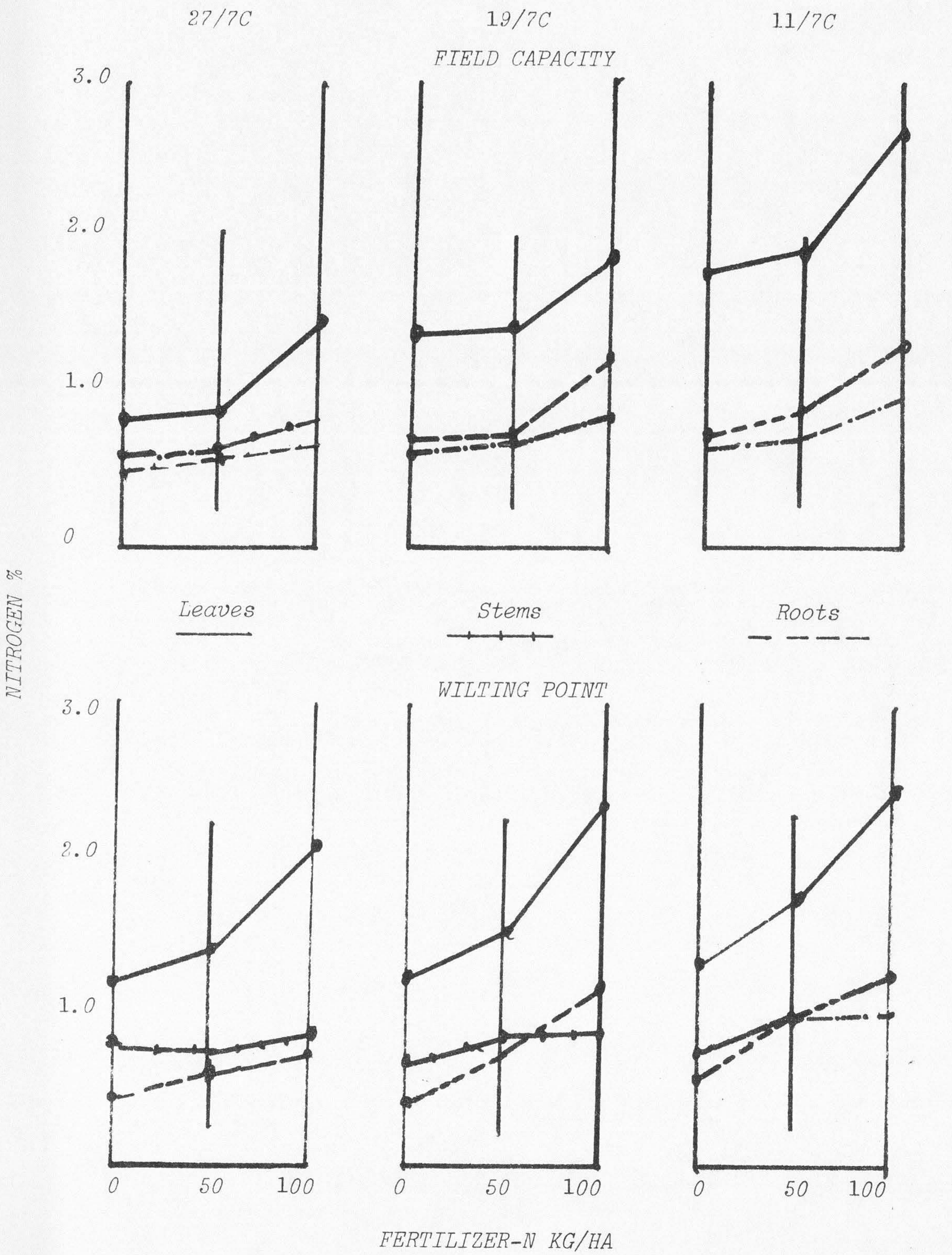

Figure 9. Nitrogen content in crested wheatgrass as influenced by three N fertilizer levels under field conditions.

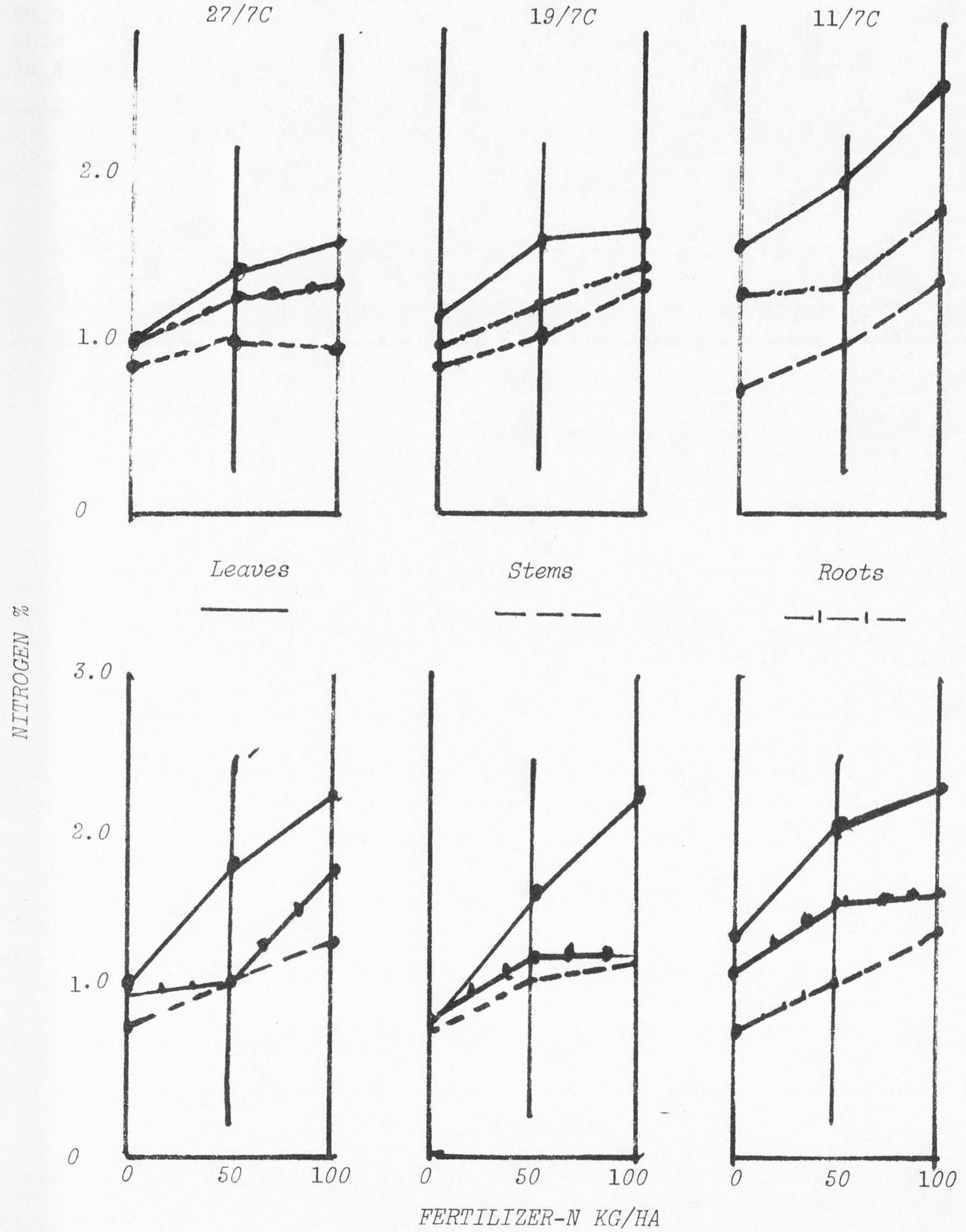

Figure 10. Nitrogen content in fourwing saltbush as influenced by three N fertilizer levels under field conditions.

Table 8. Treatment mean comparisons for nitrogen (%) in leaves, stems and roots of crested wheatgrass and fourwing saltbush maintained for 60 days in growth chambers under three temperature regimes, two water stress regimes and three N fertilizer levels (grams). (See Table 16 in Appendix for Analysis of Variance).

Treatment	Mean*		
	Leaves	Stems	Roots
Species			
4-wing	N-S	1.0 a	1.3 a
crested wheatgrass	N-S	0.7 b	0.7 b
Temperature			
11/7 C	2.0 a	N-S	1.2 a
19/7 C	1.6 b	N-S	0.9 b
27/7 C	1.4 b	N-S	1.0 b
N Fertilizer (kg/ha)			
100	2.0 a	1.1 a	1.2 a
50	1.6 b	0.9 ab	1.1 ab
0	1.1 c	0.8 b	0.8 b
Water Stress			
FC	N-S	N-S	N-S
WP	N-S	N-S	N-S
Species X Temperature			
4-wing 11/7 C	2.0 a	1.1 a	1.5 a
4-wing 19/7 C	1.5 b	1.0 a	1.2 b
4-wing 27/7 C	1.5 b	1.0 a	1.3 ab
cwg 11/7 C	2.0 a	0.9 a	0.8 c
cwg 19/7 C	1.6 b	0.8 ab	0.7 c
cwg 27/7 C	1.3 b	0.6 b	0.7 c
Species X N Fertilizer			
4-wing 100	2.0 a	1.2 a	1.5 a
4-wing 50	1.8 a	1.1 a	1.4 a
4-wing 0	1.2 b	0.8 bc	1.0 b
cwg 100	2.1 a	1.0 ab	0.9 bc
cwg 50	1.4 b	0.7 c	0.7 c
cwg 0	1.3 b	0.5 c	0.6 c
Temperature X Water Stress			
27/7 C FC	1.2 c	N-S	N-S
27/7 C WP	1.6 b	N-S	N-S
19/7 C FC	1.5 b	N-S	N-S
19/7 C WP	1.6 b	N-S	N-S
11/7 C FC	2.0 a	N-S	N-S
11/7 C WP	2.0 a	N-S	N-S
Fertilizer X Water Stress			
0 FC	1.3 d	N-S	N-S
0 WP	1.2 d	N-S	N-S
50 FC	1.6 c	N-S	N-S
50 WP	1.8 bc	N-S	N-S
100 FC	1.9 ab	N-S	N-S
100 WP	2.2 a	N-S	N-S

* Means followed by different letters are significant at 0.05 level.
All other interactions were nonsignificant at 0.05 level.

(50 kg N/ha) did not change the N percentage of leaves, stems or roots. However, heavy N fertilization (100 kg N/ha) significantly increased the nitrogen percent in leaves and stems of crested wheatgrass. Roots did not respond to nitrogen fertilization treatment.

Water stress treatments did not change the nitrogen concentration at each N fertilizer level. The effect of water stress on the N concentration within each temperature regime was noticed only in leaves at 27/7C.

Carbohydrate reserves

At the end of the 60 day study period, total nonstructural carbohydrates (TNC) were higher in crested wheatgrass than in fourwing saltbush (Table 9). Plant response to the temperature, water stress and N treatments varied in the storage organs of both species (Figures 11 and 12).

The highest TNC concentration was noticed in roots followed by stems and leaves (Table 10). The effects of temperature treatments on TNC content were evident in leaves of crested wheatgrass only.

Crested wheatgrass at 11/7C or 19/7C contained equal levels of TNC in leaves but these were significantly higher than in plants grown at 27/7C. Fourwing saltbush did not respond to temperature treatments.

Leaves and roots of crested wheatgrass reacted positively to the species X fertilizer combination. Crested wheatgrass contained more TNC in leaves and roots at 50 kg N/ha than the plants at zero or 100 kg N/ha respectively. The TNC of fourwing saltbush was not affected

Table 9. Total nonstructural carbohydrate (TNC) percent in leaves, stems and roots of crested wheatgrass and fourwing saltbush maintained for 60 days under three temperature regimes, two water stress regimes and three N fertilizer levels. The values are means of four replications.

Obs	Temperature Regimes								
	27/7c day/night			19/7c day/night			11/7c day/night		
	Nitrogen Kg/ha			Nitrogen Kg/ha			Nitrogen Kg/ha		
	0	50	100	0	50	100	0	50	100
CRESTED WHEATGRASS	PLANTS MAINTAINED NEAR FIELD CAPACITY								
Leaves	8.1	9.3	7.4	9.3	11.3	9.0	10.7	10.6	9.6
Stems	10.2	11.0	9.6	10.2	11.8	9.7	11.3	12.1	11.4
Roots	13.6	15.1	12.8	14.3	16.0	14.2	14.8	15.2	13.8
	PLANTS MAINTAINED NEAR WILTING POINT								
Leaves	9.2	10.6	8.4	11.5	12.6	11.0	11.1	12.8	11.5
Stems	10.6	11.8	10.1	12.9	13.7	12.0	12.1	12.9	12.4
Roots	14.5	16.5	13.6	16.3	17.7	14.7	15.1	15.8	14.9
FOURWING SALTBUSH	PLANTS MAINTAINED NEAR FIELD CAPACITY								
Leaves	4.1	4.8	4.2	4.9	5.6	4.7	4.6	5.3	4.5
Stems	5.6	6.3	4.9	5.9	6.8	6.1	5.8	6.4	5.7
Roots	7.9	10.1	7.6	8.3	11.4	8.4	8.6	9.6	8.9
	PLANTS MAINTAINED NEAR WILTING POINT								
Leaves	5.1	5.9	5.9	4.8	5.6	6.9	5.3	6.9	7.1
Stems	6.8	7.8	8.3	6.7	7.5	7.9	6.4	7.1	7.6
Roots	9.3	12.1	11.8	10.1	10.9	11.9	11.0	13.8	12.2

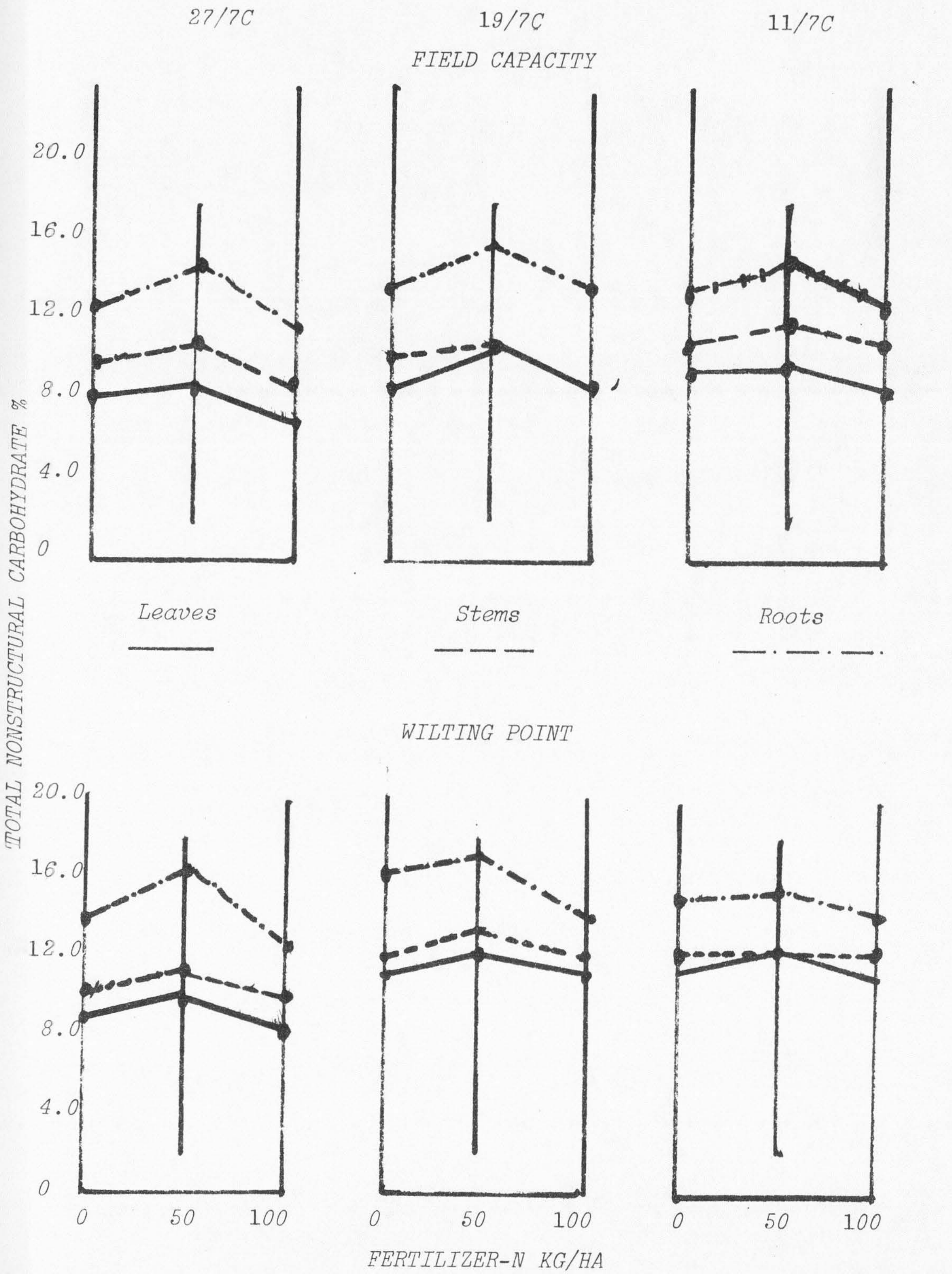

Figure 11. TNC content in leaves, stems and roots of crested wheatgrass as influenced by three N fertilizer levels under field condtions.

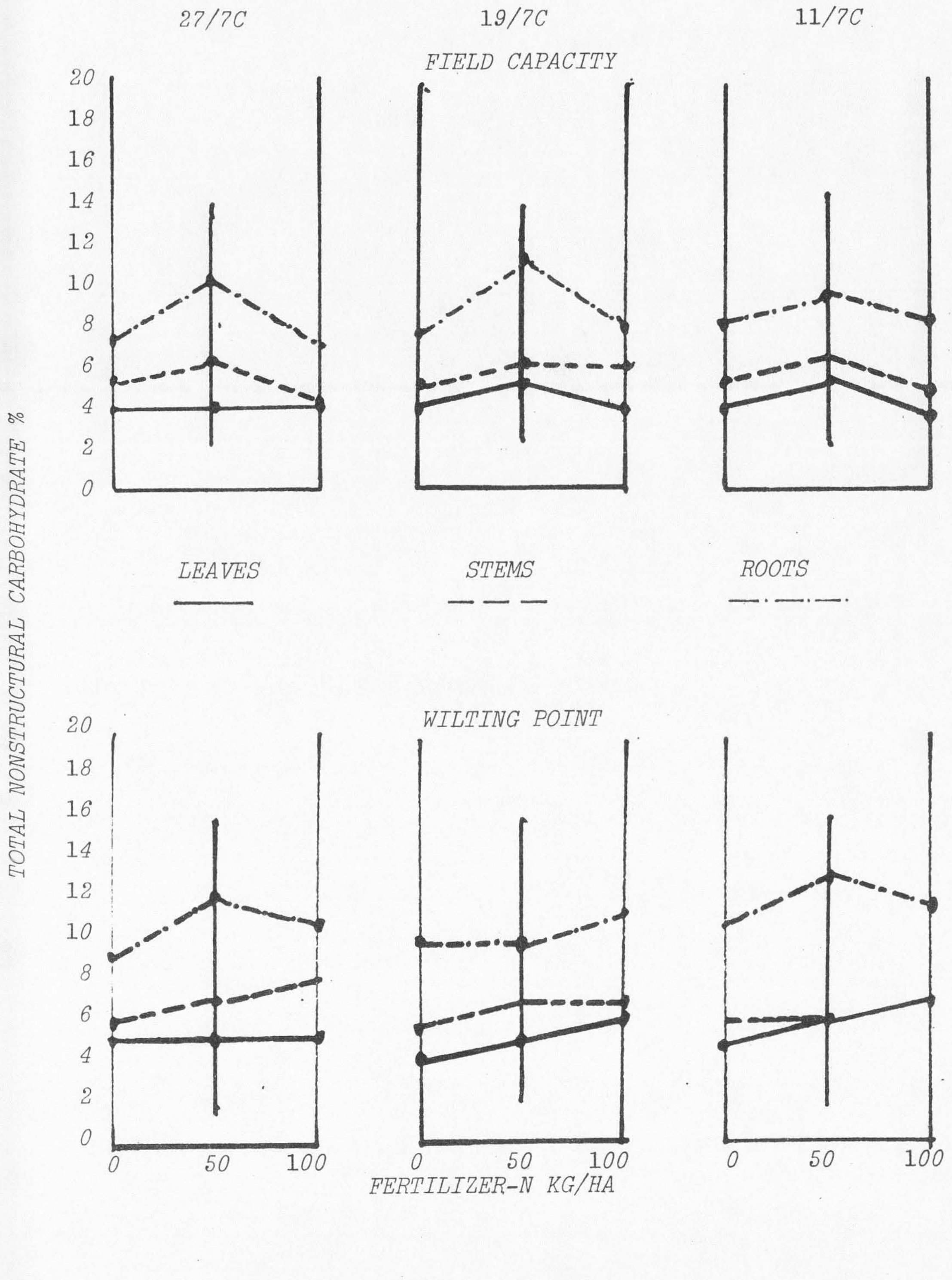

Figure 12. TNC content in leaves and stems of fourwing saltbush as influenced by three N fertilizer levels under field conditions.

Table 10. Treatment mean comparisons for total nonstructural carbohydrate (%) in leaves, stems and roots of crested wheatgrass and four-wing saltbush maintained for 60 days in growth chamber under three temperature regimes, two water stress regimes and three N fertilizer levels. (See Table 17 in Appendix for Analysis of Variance).

Treatment		Mean*		
		Leaves	Stems	Roots
Species				
cwg		10.2 a	11.4 a	14.9 a
4-wing		5.3 b	6.7 b	10.2 b
Temperature				
11/7 C		8.3 a	N-S	N-S
19/7 C		8.1 a	N-S	N-S
27/7 C		6.9 b	N-S	N-S
N Fertilizer (Kg/ha)				
0		7.4 b	8.7 b	11.9 b
50		8.4 a	9.7 a	13.7 a
100		7.5 b	8.8 b	12.1 b
Water Stress				
FC		N-S	N-S	N-S
WP		N-S	N-S	N-S
Species X Temperature				
cwg	11/7 C	11.1 a	N-S	N-S
cwg	19/7 C	10.8 a	N-S	N-S
cwg	27/7 C	8.8 b	N-S	N-S
4-wing	11/7 C	5.6 c	N-S	N-S
4-wing	19/7 C	5.4 c	N-S	N-S
4-wing	27/7 C	5.0 c	N-S	N-S
Species X N Fertilizer				
cwg	0	9.9 b	N-S	14.7 b
cwg	50	11.2 a	N-S	16.1 a
cwg	100	9.5 b	N-S	14.0 b
4-wing	0	4.8 c	N-S	9.2 c
4-wing	50	5.7 c	N-S	11.3 c
4-wing	100	5.6 c	N-S	10.1 c
Species X Water Stress				
cwg	FC	10.9 a	12.1 a	15.5 a
cwg	WP	9.5 a	10.8 a	14.4 a
4-wing	FC	4.8 b	5.9 b	8.9 b
4-wing	WP	6.0 b	7.5 b	11.0 b

* Treatment means followed by different letters are significant at 0.05 level. Remaining interactions were nonsignificant at 0.05 level.

by the different nitrogen fertilizer levels (Table 10). The effect of water stress within each species was also nonsignificant at 0.05 level.

Field Experiment I

Plant biomass

Nitrogen fertilization significantly increased the fall and spring biomass of crested wheatgrass (Figure 13). There was a sharp increase in the fall forage production of crested wheatgrass between application of 0 and 50 kg N/ha. However, there was no significant increase in yield between 50 kg N/ha and 100 kg N/ha. On the average, the increase in the fall dry matter yield of crested wheatgrass was 17[illegible] and 198 percent greater than the control with the application of 50 and 100 kg N/ha respectively. During the spring, dry matter yield of crested wheatgrass responded incrementally to the three fertilizer levels.

Fall fertilization significantly increased the yield of fourwing saltbush (Figure 14). With the application of nitrogen at 50 and 100 kg N/ha the incremental yield increase was 36 and 73 percent respectively. Fall fertilization also increased the spring regrowth of fourwing saltbush. The increase in dry matter yield due to 50 and 100 kg N/ha fertilization was 76 and 100 percent respectively as compared to the control.

Nitrogen content

During three different sampling periods of summer, fall and spring, crested wheatgrass showed significant fluctuations in nitrogen

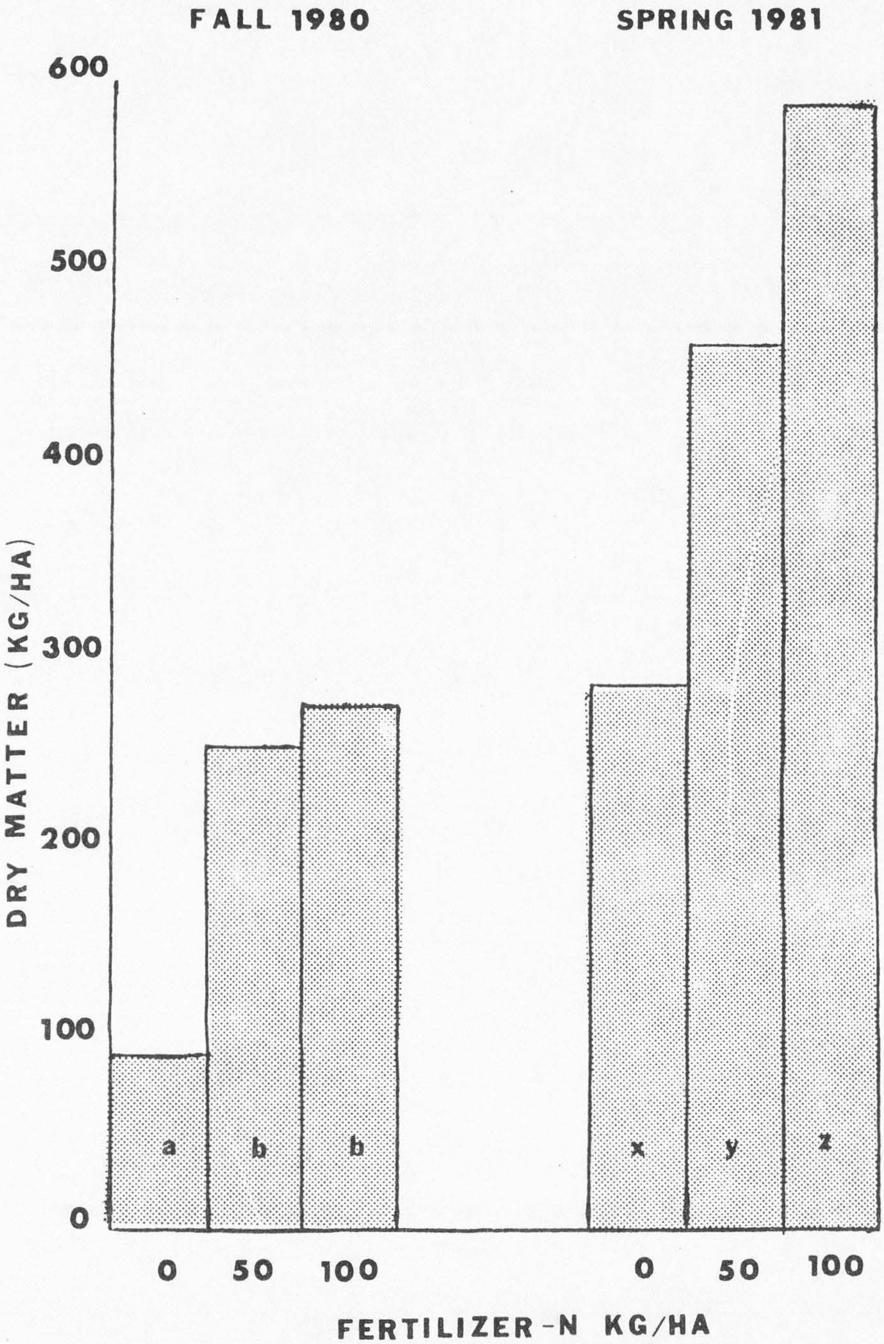

Figure 13. Dry matter yield of crested wheatgrass as influenced by three N fertilizer levels. Values represent means of five replications. Bars containing different letters are significantly different at 0.05 level.

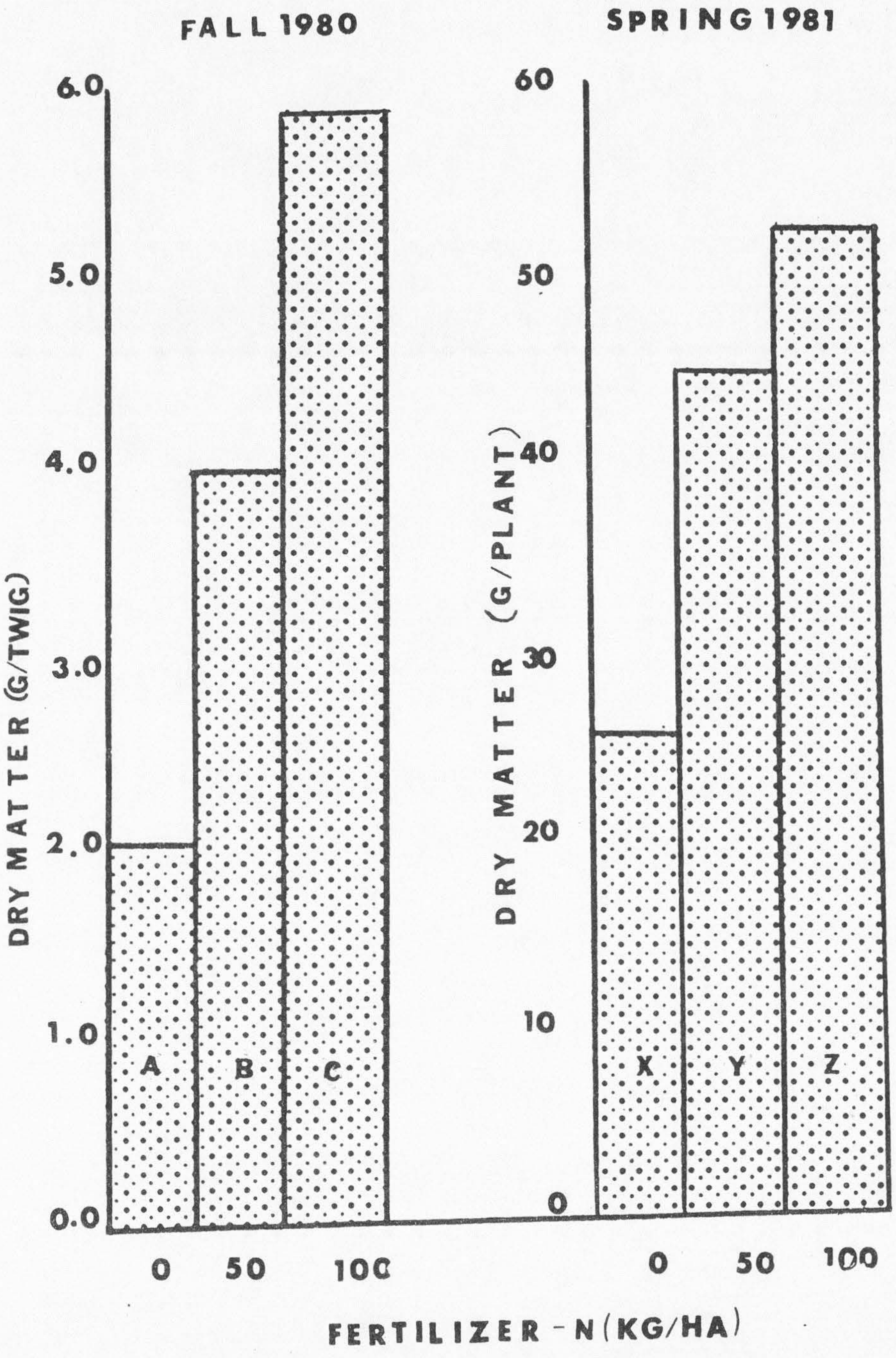

Figure 14. Dry matter yield of fourwing saltbush as influenced by three N fertilizer levels. Values represent means of five replications. Bars containing different letters are significantly different at 0.05 level.

percent (Figure 15). In the late summer 1980, the nitrogen concentration in unfertilized crested wheatgrass was lower than in the following fall or spring regrowth. Every storage organ had a different response to nitrogen treatments as well as growing season.

Leaves of crested wheatgrass contained a lower nitrogen percent in the summer than in the fall or spring growing season. Nitrogen fertilization during the fall did not affect leaf N percent. However in the spring, N concentration in leaves significantly increased as a function of fertilization.

In the summer, nitrogen percent in stems of crested wheatgrass was lower than in fall or spring. Fall nitrogen fertilization significantly increased the nitrogen level of fall and spring stem regrowth.

Nitrogen percent in roots also varied during the summer, fall and spring growing season. At the end of fall, 50 and 100 kg N/ha fertilization caused an equally significant increase in nitrogen percent of roots. The same trend was noticed for spring regrowth.

Leaf nitrogen percent of unfertilized fourwing saltbush plants did not change during the summer, fall and spring growing seasons (Figure 16). In the fall, 50 kg N/ha fertilizer increased the N percent of leaves. However, the difference between unfertilized plants and those receiving 100 kg N/ha was nonsignificant.

Unlike leaves, the stems of fourwing saltbush changed in N percent through summer and fall. However, the difference between N percent of fall and spring stem regrowth was nonsignificant. In the fall, fertilization with 50 kg N/ha increased N percent of stems more than did the zero or 100 kg N/ha rate. During the spring, only

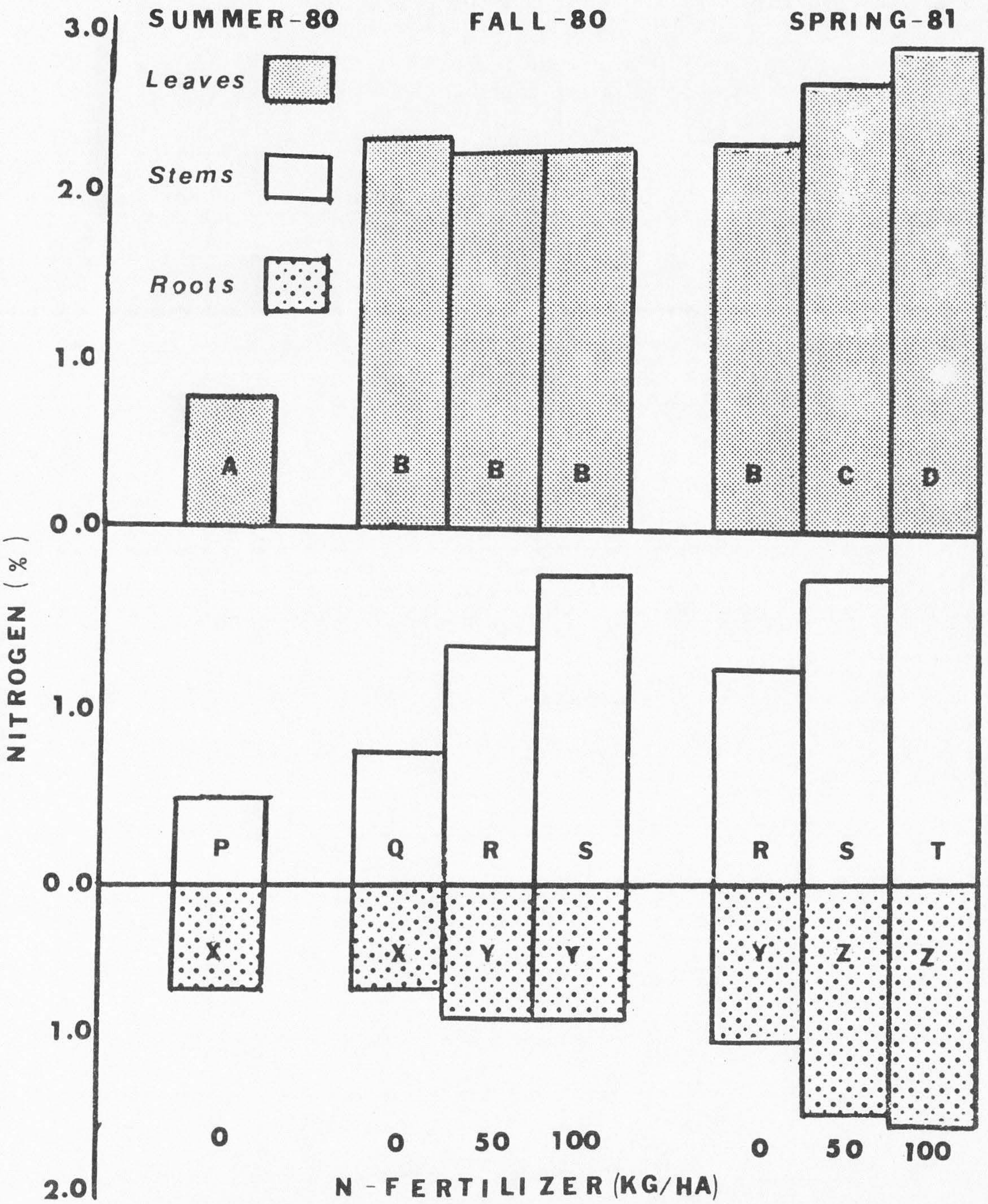

Figure 15. Nitrogen content in crested wheatgrass as influenced by three N fertilizer levels under field conditions. Bars containing different letters are significantly different at 0.05 level.

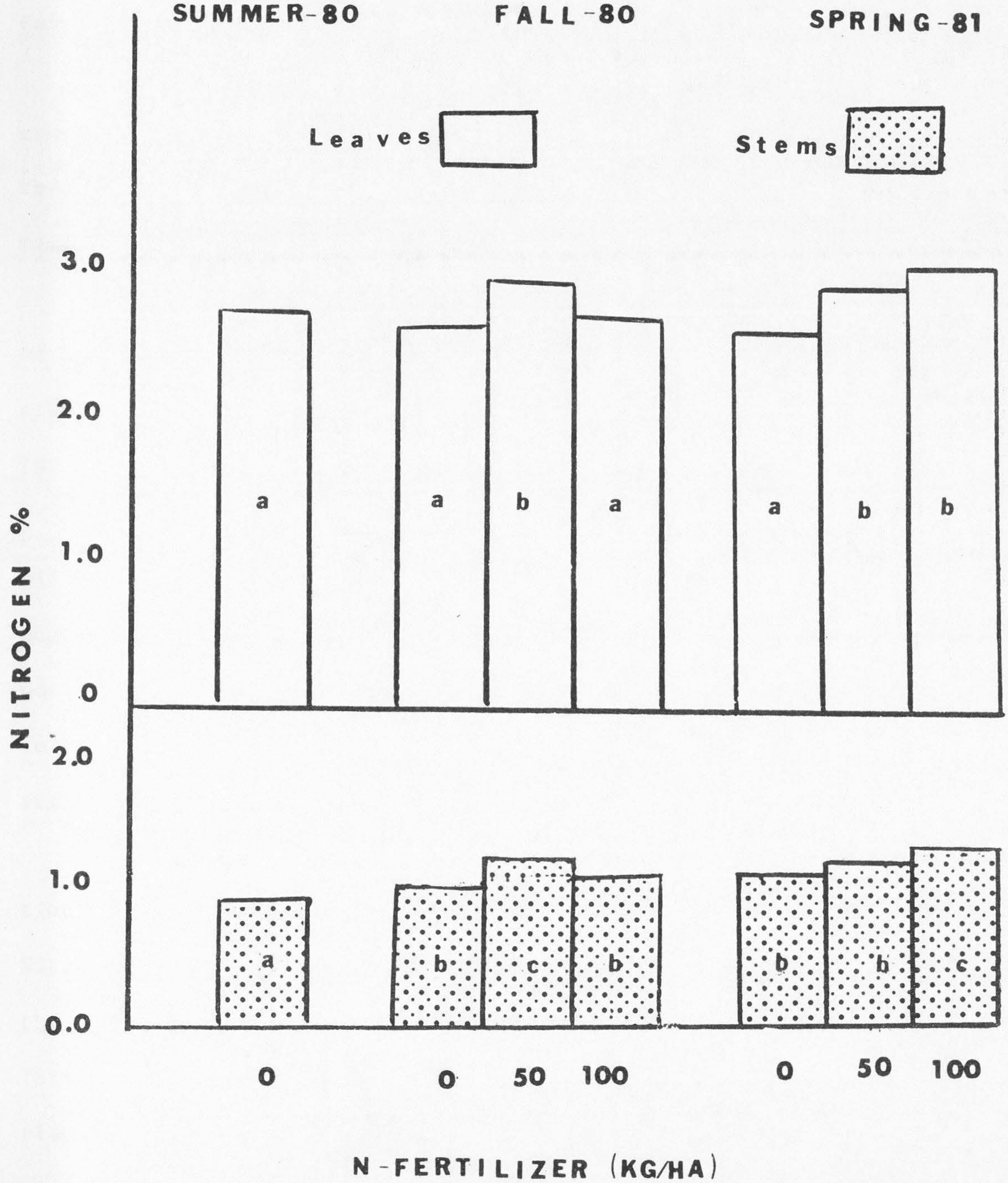

Figure 16. Nitrogen content in fourwing saltbush as influenced by three N fertilizer levels under field conditions. Bars containing different letters are significantly different at 0.05 level.

the high fertilization rate (100 kg N/ha) resulted in a high N percent of fourwing saltbush stems.

Carbohydrate reserves

The concentration of total nonstructural carbohydrate (TNC) in crested wheatgrass and fourwing saltbush plants generally changed through the summer, fall and spring growing seasons. However, the magnitude of TNC content varied among storage organs.

Roots of crested wheatgrass contained the highest concentration of TNC followed by stems and leaves (Figure 17). There was a significant decrease in leaf TNC from summer to fall. However, the TNC of leaves remained constant for the fall and spring regrowth.

The TNC content in stems of crested wheatgrass changed through different growing seasons. Nitrogen fertilization increased the TNC content in stems during fall. No difference in TNC of stems was noticed between the 50 and 100 kg N/ha fertilizer level. Fall fertilization did not affect the subsequent TNC concentration in stems during the spring regrowth period.

The roots of crested wheatgrass contained higher TNC concentrations during the summer than in the fall or spring growing season. Nitrogen fertilization did not affect the TNC levels of roots in the fall. However, in the spring, the TNC percent of the roots of fertilized crested wheatgrass plants was higher than unfertilized plants (Figure 17).

The effect of different phenological stages of development was also noticed on the TNC percent in leaves and stems of fourwing saltbush. Root samples were not collected to avoid damage to the

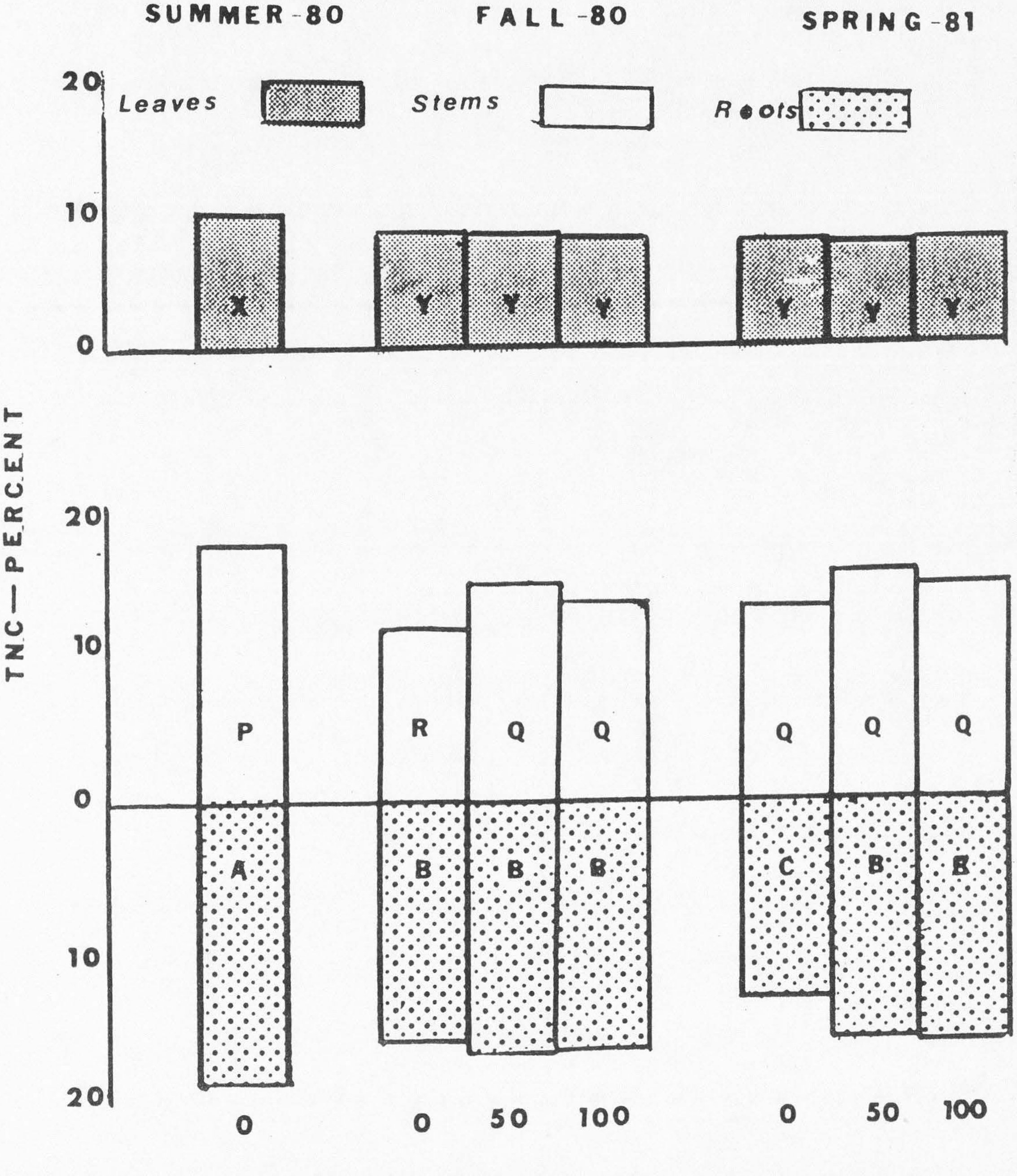

Figure 17. TNC content in leaves, stems and roots of crested wheatgrass as influenced by three N fertilizer levels. Bars containing different letters are significantly different at 0.05 level.

plants presently under seed production studies. The TNC percent in leaves decreased between summer and fall. However, no difference was noticed in the leaves of unfertilized plants between fall and spring. Nitrogen fertilization did not affect the TNC in leaves during fall regrowth but in the spring it did increase leaf TNC percent (Figure 18).

The TNC level in stems of fourwing saltbush decreased between summer and fall but remained constant between fall and spring. Nitrogen fertilization (50 kg/ha) increased the TNC in stems during fall but as the amount of N was increased to 100 kg/ha, the TNC concentration in stems dropped to less than in unfertilized plants. In the spring, low amounts of fall applied nitrogen (50 kg/ha) did not affect the TNC percent. However, a significant decrease in TNC occurred to plants that had been fertilized at the 100 kg N/ha level.

Field Experiment II

Plant biomass

When averaged across all treatments, plant biomass of crested wheatgrass was significantly increased as availability of water to plants was increased (Figure 19). The plant biomass was also increased due to nitrogen fertilizer treatments. Plants fertilized at the 50 or 100 kg N/ha level produced an equal amount of dry matter under dry conditions. However, it was significantly more than the biomass obtained from unfertilized plants maintained under dry conditions.

In the medium irrigation treatment, a moderate amount of nitrogen fertilizer (50 kg N/ha) did not increase plant biomass. However, as

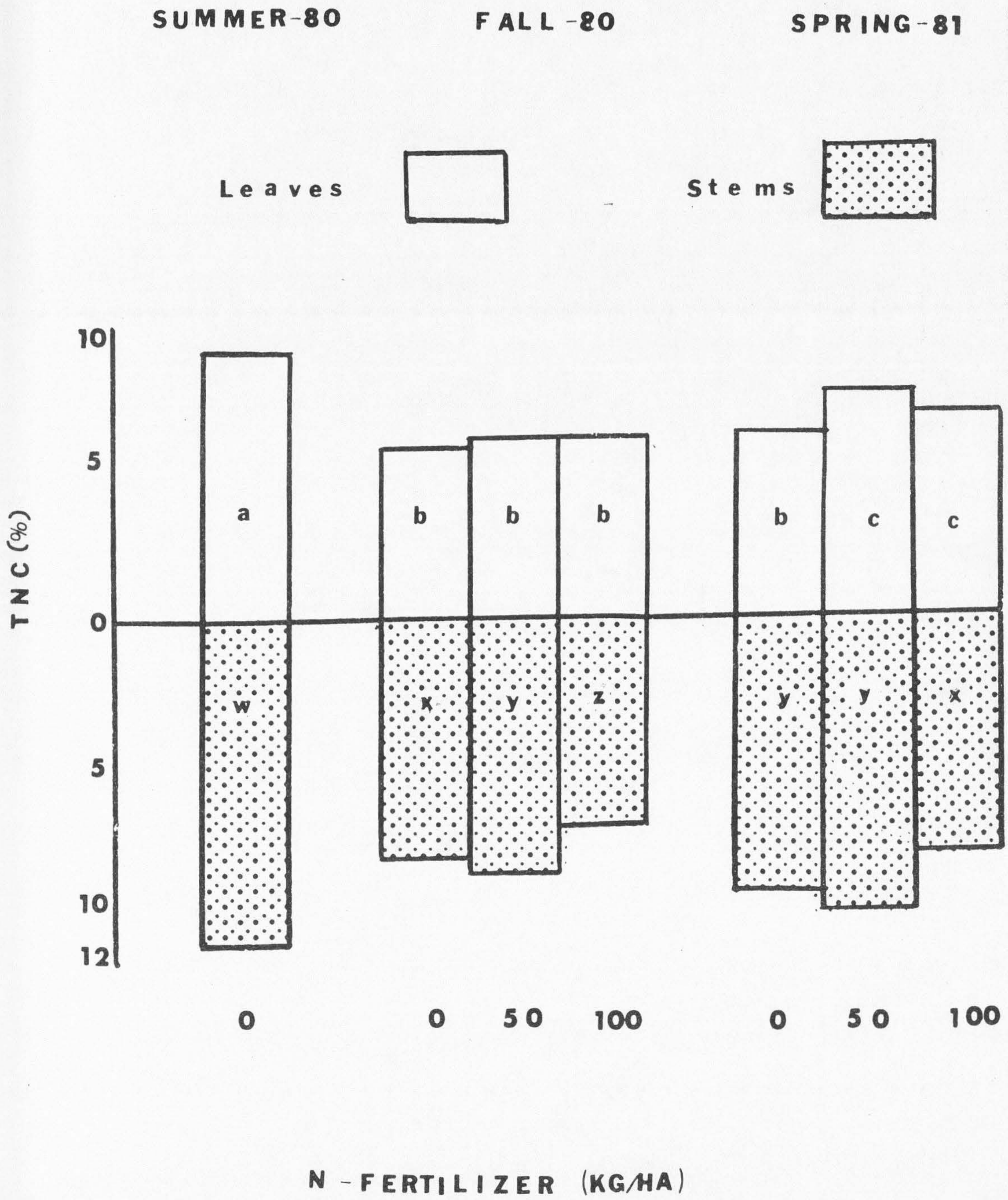

Figure 18. TNC content in leaves and stems of fourwing saltbush as influenced by three N fertilizer levels. Bars containing different letters are significantly different at 0.05 level.

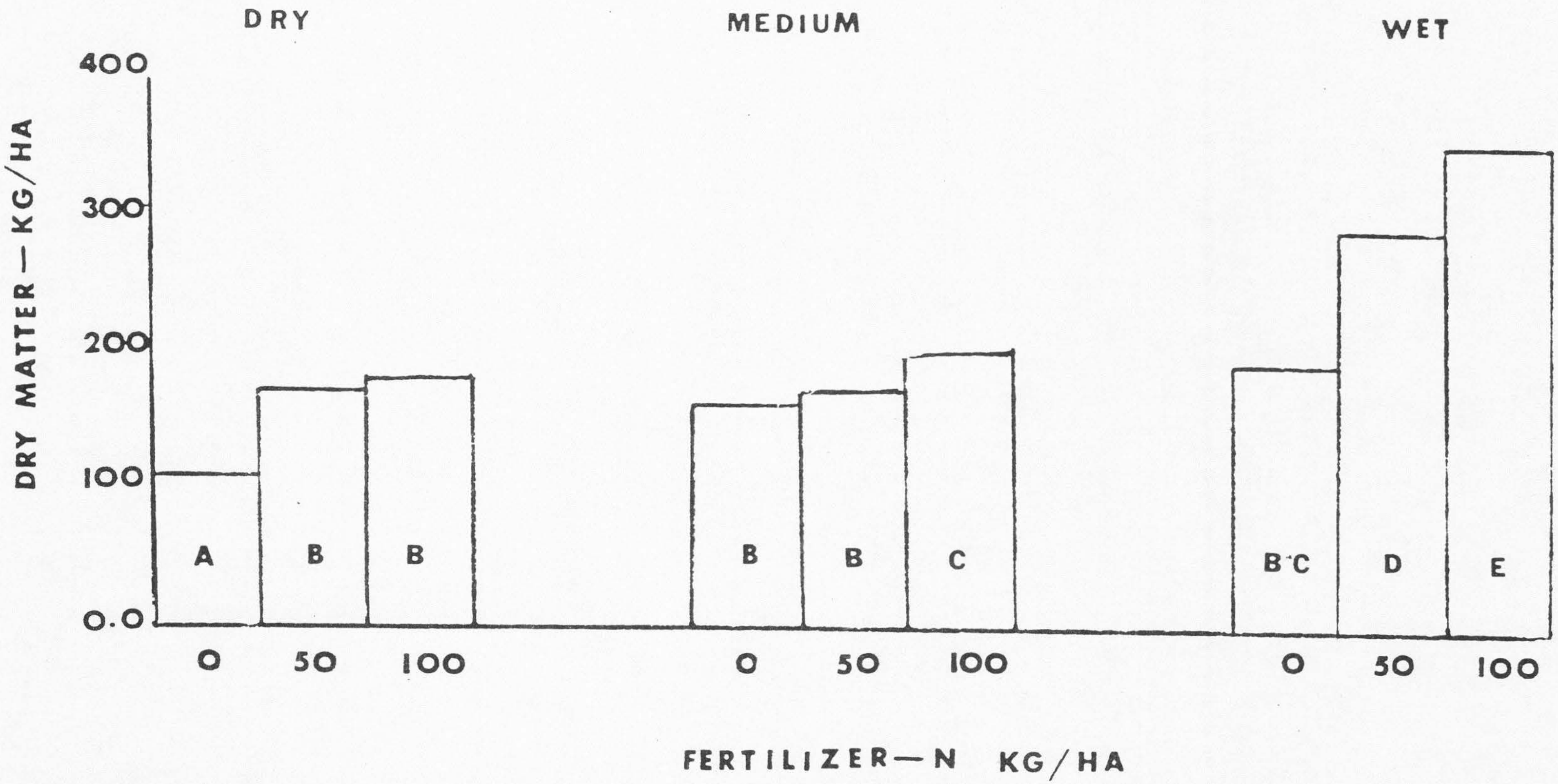

Figure 19. Dry matter yield of crested wheatgrass plots as influenced by three N fertilizer levels and three irrigation regimes. Values are mean of four replications. Bars containing different letters indicate significant differences for each treatment at 0.05 level.

the amount of nitrogen was increased to 100 kg N/ha, a significant increase in dry matter yield of crested wheatgrass was noticed. Under wet conditions plant biomass was significantly increased with the increase in nitrogen level.

Dry matter yield of fourwing saltbush was also increased due to nitrogen and irrigation treatments (Figure 20). Under dry conditions only the 100 kg N/ha fertilizer level had a significant increase in the dry matter yield of fourwing saltbush which was equal to the biomass obtained from unfertilized plants maintained under medium or wet conditions.

In the medium irrigation regime, dry matter yield of fourwing saltbush was increased only when fertilizer at a rate of 100 kg N/ha was applied. However, under wet conditions plant biomass increased with the increase in nitrogen fertilizer level.

Root biomass

Crested wheatgrass and fourwing saltbush differed in root distribution as a function of soil depth (Table 11). In the top 10 cm of soil, crested wheatgrass maintained 35 percent of its total root biomass. The corresponding percentage for fourwing saltbush at same soil depth was 27. Eighty-two percent of crested wheatgrass roots were within the top 40 cm soil depth. On the other hand fourwing saltbush maintained 60 percent of its total root biomass within the top 40 cm of soil depth. Forty percent of fourwing saltbush roots were below 40 cm soil. The root biomass of crested wheatgrass below 40 cm soil depth was only 18 percent.

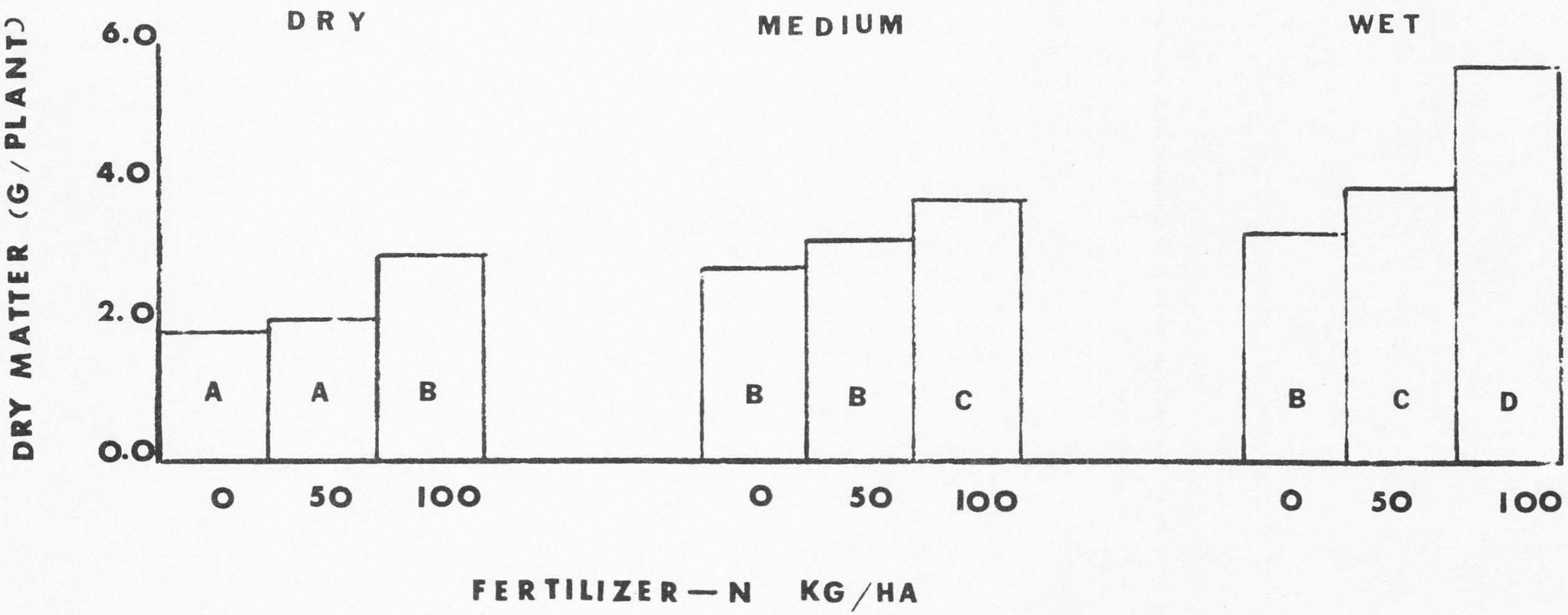

Figure 20. Dry matter yield of fourwing saltbush plots as influenced by three N fertilizers and three irrigation regimes. Values are means of four replications. Bars with different letters indicate significant differences at 0.05 level.

Table 11. Root biomass of crested wheatgrass and fourwing saltbush plants at Nephi Dryland Research Station. Values are mean of three replications.

Soil Depth (cm)	Crested Wheatgrass			Fourwing Saltbush		
	gm/ plant	percent of total	cumulative (%)	gm/ plant	percent of total	cumulative (%)
0-5	4.8	17		2.6	12	
5-10	5.0	18	35	3.2	15	27
10-15	3.2	12	47	2.1	10	37
15-20	2.6	10	57	1.9	9	46
20-30	3.9	14	71	1.8	8	54
30-40	3.1	11	82	1.6	6	60
40-50	2.2	9	91	3.1	15	75
50-70	1.4	5	96	2.5	11	86
70 and below	1.1	4	100	3.0	14	100
	27.3	100	100	21.8 1/	100	100

1/ Tap roots not included since they are not part of the moisture/ nitrogen absorbing system of the plant.

Soil water content

Soil water content of crested wheatgrass and fourwing saltbush plots varied among irrigation treatments as well as with soil depth (Table 12). No significant difference was noticed between the two observations recorded on July 14, 1981 and September 12, 1981, except that the water content of dry plots in the top 10 cm soil depth was greater on September 12, 1981 than at the time of the first observation recorded on July 14, 1981. This variation was due to 5 mm of rainfall received on September 10, 1981.

Results of the first and second observations showed no difference between soil water content of crested wheatgrass and fourwing saltbush plots for the respective irrigation treatments. In both observations, water content of plots increased with the increase in amount of irrigation (Table 12).

Soil water content under dry conditions gradually increased with the increase in soil depth. In the medium soil moisture regime, water percolated to 30 cm soil depth. The effects of the wet irrigation treatment on soil water content were noticed down to 40 cm soil depth. The soil water content below 40 cm soil depth was not affected by irrigation treatments.

Soil NO_3-N

Soil nitrate concentration as a function of soil depth was controlled by water percolation in both crested wheatgrass and fourwing saltbush plots (Figures 21 and 22). When averaged across all treatments, no difference in soil NO_3-N was found between crested wheatgrass and fourwing saltbush plots.

Table 12. Soil water content θm (% moisture by weight) of crested wheatgrass and fourwing saltbush plots at Nephi Dryland Research Station. Values are means of four replications.

Date	Soil depth (cm)	Soil Water Content (θm)											
		Crested Wheatgrass Plots						Fourwing Saltbush Plots					
		Soil Moisture Regimes						Soil Moisture Regimes					
		Dry		Medium		Wet		Dry		Medium		Wet	
7-14-81	5	0.08a	X	0.18bc	Y	0.21cd	Z	0.06a	X	0.19b	Y	0.21c	Z
	10	0.10ab	X	0.20d	Y	0.23d	Z	0.08a	X	0.20b	Y	0.22c	Z
	20	0.12bc	X	0.19cd	Y	0.20bc	Y	0.11b	X	0.20b	Y	0.20bc	Y
	30	0.11b	X	0.17b	Y	0.17a	Y	0.13bc	X	0.18a	Y	0.19b	Y
	40	0.14cd	X	0.15a	X	0.17a	Y	0.14cd	X	0.18a	Y	0.18b	Y
	50	0.14cd	X	0.14a	X	0.18ab	Y	0.16de	X	0.17a	XY	0.15a	X
	70	0.15d	X	0.17b	X	0.16a	X	0.17e	X	0.16a	X	0.15a	X
	90	0.16d	X	0.16ab	X	0.16a	X	0.17e	X	0.16a	X	0.16a	X
9-12-81	5	0.10a	X	0.17a	Y	0.19bc	Z	0.10a	X	0.18b	YZ	0.20d	Z
	10	0.10a	X	0.19b	Y	0.21c	Z	0.11a	X	0.11a	Y	0.20d	Z
	20	0.11a	X	0.18ab	Y	0.20c	Z	0.11a	X	0.18b	Y	0.18bc	Y
	30	0.13b	X	0.18ab	Y	0.20c	Z	0.13b	X	0.17ab	Y	0.19c	YZ
	40	0.15c	X	0.16a	X	0.18b	Y	0.14b	X	0.16a	Y	0.17b	XY
	50	0.15c	X	0.17a	X	0.18b	X	0.16c	X	0.15a	X	0.16ab	X
	70	0.17c	X	0.17a	X	0.16a	X	0.15bc	X	0.16a	X	0.15a	X
	90	0.16c	X	0.16a	X	0.17ab	X	0.16c	X	0.15a	X	0.17b	X

Note: 1) Means followed by different small letters (vertical columns) are significant at 0.05 level.
2) Means followed by different capital letters (horizonal rows) are significant at 0.05 level.

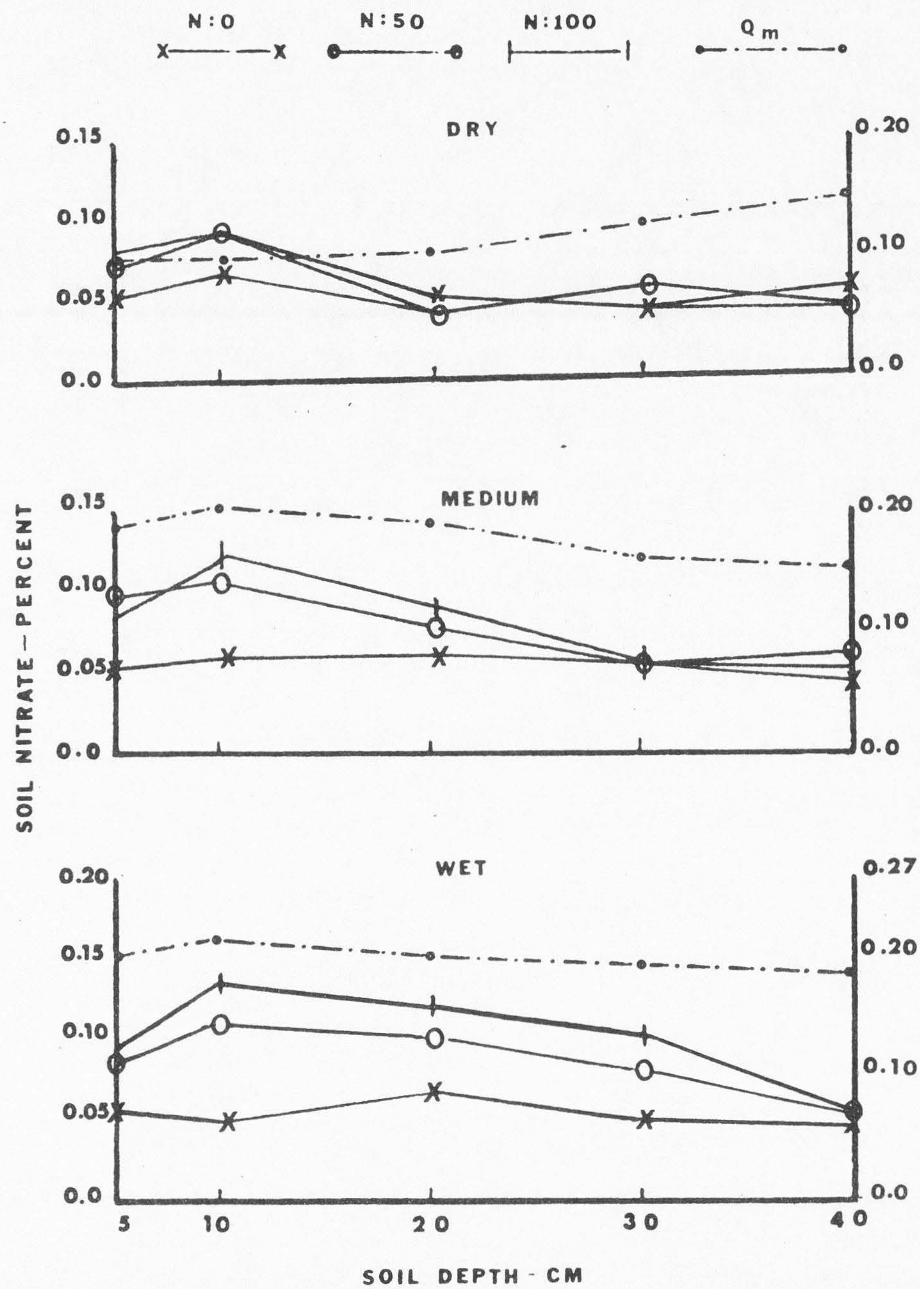

Figure 21. Soil nitrate (%) and soil water content θm (% moisture by weight) of crested wheatgrass pastures as influenced by three nitrogen fertilizer levels and three irrigation regimes.

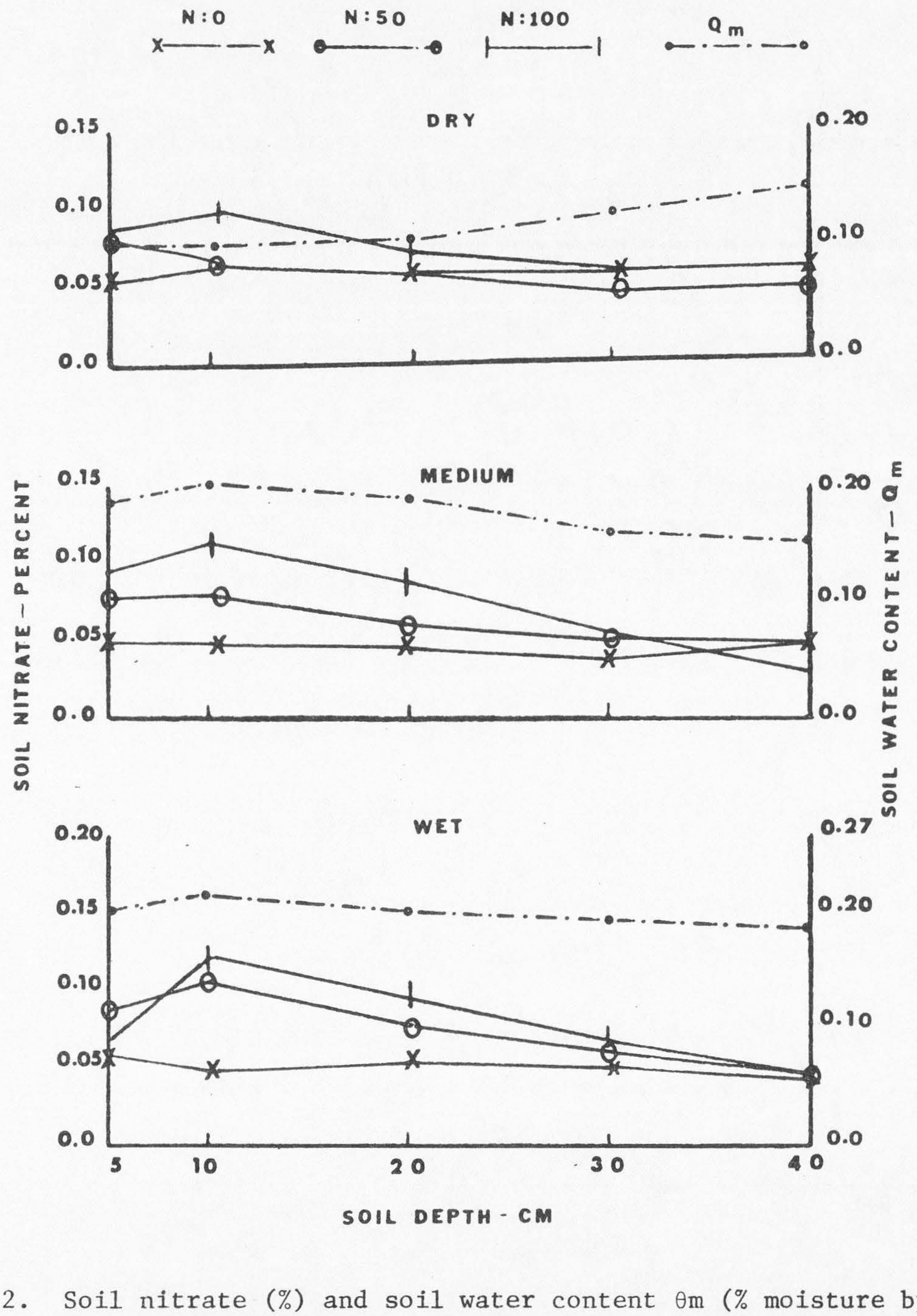

Figure 22. Soil nitrate (%) and soil water content θm (% moisture by weight) of fourwing saltbush plots as influenced by three nitrogen fertilizer and three irrigation treatments.

In unfertilized crested wheatgrass plots maintained under dry conditions the antecedent soil N decreased with soil depth (Table 13). Under dry conditions the effect of nitrogen fertilization (50 and 100 kg N/ha) on soil N was noticed only up to 10 cm soil depth. This nitrogen penetration in the soil was presumably a result of 5 mm rainfall received two days before soil nitrogen sampling.

The antecedent nitrogen in crested wheatgrass plots maintained at medium soil moisture regime was equally distributed with soil depth. Nitrogen fertilization (50 and 100 kg N/ha) increased the soil N content to 20 cm soil depth in the medium irrigation treatment. The nitrate content of soil below 20 cm depth was equal to the plots under no treatment.

Under wet conditions no difference in NO_3-N was found with soil depth in unfertilized plots of crested wheatgrass. However, nitrogen fertilizer (50 to 100 kg N/ha) penetrated to 20 cm soil depth. Below 20 cm soil depth no difference in nitrate content was noticed among plots.

Soil nitrate percent in fourwing saltbush plots showed a similar trend to crested wheatgrass plots (Table 13). In dry plots nitrogen fertilizer increased the NO_3 percent to 10 cm soil depth. However, in the medium and wet irrigation treatments nitrogen penetrated to 20 cm soil depth. The antecedent soil N was equally distributed along soil depth in all irrigation treatments.

Table 13. Soil NO_3-N percent in crested wheatgrass and fourwing saltbush plots as influenced by three nitrogen fertilizer and three irrigation treatments. Values are mean of four replications.

Soil Depth (cm)	Soil Moisture Regimes: Dry, Nitrogen Level 0	Dry 50	Dry 100	Medium, Nitrogen Level 0	Medium 50	Medium 100	Wet, Nitrogen Level 0	Wet 50	Wet 100
Crested wheatgrass									
5	0.06b*	0.07b	0.09c	0.05ab	0.09c	0.08b	0.05ab	0.07b	0.09bc
10	0.07b	0.08b	0.08b	0.06b	0.10c	0.11c	0.05ab	0.10c	0.12d
20	0.05a	0.04a	0.05a	0.06b	0.07b	0.08b	0.06b	0.09c	0.10c
30	0.04a	0.05a	0.04a	0.05ab	0.05a	0.06a	0.04a	0.07b	0.08b
40	0.05a	0.04a	0.05a	0.04a	0.04a	0.05a	0.04a	0.05a	0.05a
Fourwing saltbush									
5	0.05a	0.08c	0.08b	0.05a	0.07c	0.09bc	0.05a	0.09c	0.08b
10	0.06a	0.06b	0.09b	0.04a	0.08c	0.10c	0.06a	0.10c	0.11c
20	0.05a	0.05ab	0.06a	0.04a	0.06bc	0.08b	0.05a	0.07b	0.09b
30	0.05a	0.04a	0.05a	0.05a	0.04a	0.05a	0.05a	0.05a	0.06a
40	0.05a	0.04a	0.05a	0.05a	0.05ab	0.04a	0.05a	0.05a	0.05a

* Values followed by different letters (vertical columns) are significant at 0.05 level.

DISCUSSION

Little information is available concerning ways to increase the amount of dry matter yield during the fall period of short forage supply. Nitrogen fertilization of rangelands has increased forage production during summer growing season (Samuel et al. 1980). However, effects of nitrogen fertilization on plants during fall when temperature and soil moisture are low, have not been studied.

If nitrogen fertilization can partially compensate for the adverse effects of low temperature and low soil moisture on plant growth, important consequences in management of fall ranges may be achieved. Therefore, the findings of this study on the effects of fall nitrogen fertilization on the water use efficiency, plant production, nitrogen content and carbohydrate reserves of crested wheatgrass and fourwing saltbush provide useful data to guide management programs.

Water Use Efficiency

Water use efficiency is a function of the ability of plants to control water loss through its leaves, to exploit soil water and to produce more biomass (Teare 1977). In addition, environmental factors also affect the plant response. The controlled growth chamber environment provided an opportunity to isolate the impact of different temperature regimes, water stress regimes and nitrogen fertilizer levels on the water use efficiency of crested wheatgrass and fourwing saltbush.

In this study a significant increase in plant water use efficiency occurred as the temperature was increased in growth chambers. The six percent increase in water use efficiency by crested wheatgrass and fourwing saltbush when grown at a high air temperature (27/7C) may be attributed to the increased biological activity--resulting in a higher growth rate.

The significant effect of temperature regimes on the water use efficiency of crested wheatgrass and fourwing saltbush suggest that during fall growing season, plant water use efficiency of plants may be decreased by low temperatures unless some other measures are taken to stimulate plant growth in the late fall when temperatures fall below the optimum required for plant growth.

When averaged across all treatments, the water use efficiency of fourwing saltbush was eight percent less at field capacity than at wilting point. Less transpiration of plants maintained at wilting point regime enabled them to withstand the dessicating effects of high temperature. The relatively low supply of available water probably could not sustain a high rate of evapotranspiration due to closure of stomata and rolling of leaves, etc.

These adaptations of plants to water stress may be to the great advantage of arid land plants, where water is scarce. However, in this situation, physical variables like solar radiation, wind, relative humidity and other environmental factors may also influence the growth and water requirements of plants (McKell and Goodin 1973, Kramer 1969, Brown 1974). Bierhuizen (1976) attributed a high water use efficiency to a favorable gradient of vapor pressure and carbon dioxide and of the magnitude of the mesophyll resistance.

The significant influence of water stress on the water use efficiency of fourwing saltbush should be given special consideration in the future studies of plant water relationships. It can be concluded that under controlled environmental conditions, fourwing saltbush plants at field capacity may waste the extra water available to them. However, this may be too hasty a conclusion to apply under the complex environmental conditions prevailing in the field. Lemon et al. (1957) found no effects of moisture stress on net radiation of plants considered to be important for transpiration. Shouse et al. (1981) found a significant increase in water use efficiency in cowpeas under a high water-stress.

When averaged across all treatments the water use efficiency of crested wheatgrass and fourwing saltbush increased as the amount of nitrogen fertilizer was increased from 0 to 100 kg N/ha level. Nitrogen fertilizer increased the plant biomass with less water consumption. Dwyer and DeGarmo (1970) in a greenhouse study reported that fourwing saltbush was an efficient user of water. The results are further supported by Call (1981), Smika et al (1965) and Bravdo et al. (1981). Williams et al. (1979) reported an increase in water use efficiency of grasses due to nitrogen fertilization.

The data also suggested that nitrogen (50 and 100 kg/ha) stimulated growth under high water stress regimes which produced an increase of dry matter yield. On the other hand, the high stress regime retarded the transpiration rate of crested wheatgrass and fourwing saltbush. The net result of these interactions as a result was an increase in water use efficiency. Viets (1962) has extensively reviewed the effects of fertilizers on the water use efficiency of plants. He pointed out that the stimulation of plant growth by fertilizers is mainly responsible for the observed increase of water use efficiency in plants.

The results of this research support the hypothesis that nitrogen fertilization (50 kg N/ha) increases water use efficiency of crested wheatgrass and fourwing saltbush. Though the physiological activities of crested wheatgrass and fourwing saltbush were restricted due to limited environmental conditions in growth chambers, the research gave an interesting clue for water requirement for grasses and shrubs. Under the same environmental conditions, grasses need less water to produce a gram of dry matter than shrubs. However, in the field where environmental conditions are very complex the grass-shrub response to nitrogen fertilization might be different. This is an interesting question which should be the subject of future study.

Nitrogen fertilization was more effective in increasing the water use efficiency of crested wheatgrass and fourwing saltbush under high water stress than under low stress conditions. Since fall regrowth is restricted by low precipitation, any step to conserve the meager amount of rain would be very helpful in increasing forage production during fall growing seasons.

Plant Growth Responses

Growth is defined as the progressive development of an organism. However, in this study the main concerns were with plant biomass, nitrogen content and carbohydrate reserves of crested wheatgrass and fourwing saltbush. From a range management view, the factors that influence these parameters are of great importance. Among the environmental factors known to influence plant growth, the most important are probably temperature, water supply, light and supply of nutrient elements (particularly nitrogen) (Tisdale and Nelson 1975). Light intensity in the field during fall growing season is not considered to limit plant growth. Plant response to the remining factors is discussed in the following subsections on plant biomass, nitrogen content, carbohydrate reserves and soil NO_3-N in the root zone of plants.

Plant biomass

Dry matter yield of crested wheatgrass and fourwing saltbush was significantly affected by the temperature, water stress and nitrogen fertilizer treatments under growth chamber controlled environment as well as under field conditions. The results indicated that these environmental factors had individual as well as combined influences on the plant biomass of crested wheatgrass and fourwing saltbush.

Both crested wheatgrass and fourwing saltbush perform better if temperature and soil moisture are adequate. Nitrogen fertilization under optimum environmental conditions further increases the dry matter yield of crested wheatgrass and fourwing saltbush. However, during the fall growing season plant growth is restricted by low temperature and limited soil moisture. Therefore, only those results which are relevant to the objective of the study are discussed below.

In the growth chamber experiment the dry matter yield of both species increased as a function of temperature. According to Nielsen et al. (1964), Storrier (1965) and Sosebee and Herbel (1969), photosynthesis, respiration, cell wall permeability, absorption of water and nutrients, transpiration, enzyme activity and protein coagulation increase with temperature--up to an optimum point. Low temperatures may adversely affect the growth of plants by reducing the absorption of water and minerals and moderating the effects of tissue dehydration (Weiking 1963). The high water stress caused reduction both in cell division and cell elongation, hence in growth (Kramer 1969, Lahiri and Singh 1968).

Results of the growth chamber study indicated that under the low temperature regime water stress treatments did not affect the dry matter yield of crested wheatgrass and fourwing saltbush maintained without fertilizer. Low temperatures probably reduced the movement of water in the soil resulting in less absorption of water and nutrients by plants.

With a moderate amount of nitrogen fertilizer (50 kg N/ha) forage production of crested wheatgrass and fourwing saltbush during low temperature (11/7C) and high water stress can be increased equal to the amount of dry matter produced by unfertilized crested wheatgrass and fourwing saltbush plants maintained at field capacity soil moisture regime and at optimum temperature regime (19/7C). In early fall, temperatures are adequate for plant growth. Therefore, fall fertilization (50 kg N/ha) would stimulate plant growth resulting in more productive use of the meager amount of precipitation received during the fall growing season.

Based on the dry matter yield obtained from crested wheatgrass and fourwing saltbush grown under controlled environment in a growth chamber, the hypothesis that nitrogen fertilization (50 kg N/ha) can compensate for the adverse effects of low temperature and low soil moisture appears to be valid. Nitrogen fertilization can substantially increase the dry matter of crested wheatgrass and fourwing saltbush if the environmental conditions are adequate. This is very important for the management of fall ranges where a range manager does not have many options for the manipulation of rangelands. However, economical use of range fertilization should be determined in relation to available options.

Results from both field experiments also suggest that with a moderate amount of nitrogen fertilizer (50 kg N/ha) dry matter yield of crested wheatgrass and fourwing saltbush is significantly increased. Fall fertilization does not have an adverse effect on spring regrowth. In fact, following fall fertilization, the forage production during spring is also significantly increased. Thus, plant biomass data obtained from both field experiments support hypothesis number three.

Nitrogen concentration in plants

Nitrogen is a key element in the nutrition of plants. Regardless of the form of nitrogen absorbed by plants, it is converted within the plants to the -N-, +N+, or NH_2 forms. This reduced nitrogen is then elaborated into more complex compounds and ultimately into protein. Nitrogen is an essential constituent of all living matter as it is now known. Any extra protein produced allows the leaves to grow larger and thus potentially to have a greater photosynthetic area.

The nitrogen concentration of crested wheatgrass and fourwing saltbush increased significantly in certain treatments under controlled environmental conditions in growth chambers. The N concentration in leaves and roots of crested wheatgrass increased under the cool temperature regime (11/7C) as compared to plants under medium (19/7C) or high temperature (27/7C). Stems of crested wheatgrass were not affected by temperature regimes. Nitrogen percent of leaves and stems of fourwing saltbush at 11/7C temperature was similar to plants under medium (19/7C) or high temperature (27/7C) regime. Temperature did not affect the N percent of roots. It appears that, as far as temperature is concerned, nitrogen percent of crested wheatgrass and fourwing saltbush may not change until the temperature falls to 11/7C.

During the 60-day growth chamber experiment, water stress treatments did not cause a difference between the nitrogen percent of crested wheatgrass and fourwing saltbush. This was possibly due to reduced growth and utilization of nutrients under high water stress conditions. Nitrogen accumulation in crested wheatgrass and fourwing saltbush under high water stress did not occur probably due to the limited physiological activity in plants caused by a reduced water balance of plants which moderates most physiological processes (Rumburg et al. 1964). George et al. 1971 and Kluge 1976). The expected increase in the N percent of plants maintained near field capacity was neutralized probably due to a high rate of N assimilation to support the rapid and large amount of forage produced.

The assumption that high water stress might result in a high N concentration in crested wheatgrass and fourwing saltbush did not hold true because the 60-day fall regrowth period was too short for plants to complete the critical phenological cycle such as leaf growth maturation which affects reserve substances. Therefore, it may be possible to moderately increase forage yield under limited soil moisture during short fall regrowth period without substantially reducing the N level of crested wheatgrass and fourwing saltbush.

Nitrogen fertilization is the most likely method of increasing forage quantity and quality of both native and introduced range plants. However, applying N in excess of plant needs may under some environmental conditions cause excess quantities of nitrates to accumulate in plants that are toxic to grazing animals. Therefore, a careful evaluation of prevailing environmental factors is necessary along with proper amount of N fertilization.

Fifty and 100 kg N/ha levels had an equal effect on the N percent of leaves, stems and roots of fourwing saltbush which was significantly higher than unfertilized plants. On the other hand only 100 kg N/ha rate increased the N content in leaves, stems and roots of crested wheatgrass. In a fertilizer x water stress combination increase in N percent was primarily due to the nitrogen fertilizer level. Under field conditions nitrogen in both crested wheatgrass and fourwing saltbush increased as a result of 50 kg N/ha nitrogen fertilization.

From the results of the study it is evident that fourwing saltbush had a higher N concentration in all storage organs than crested wheatgrass. Therefore even a moderate amount of nitrogen fertilizer (50 kg N/ha) increased the N percent of fourwing saltbush.

The hypothesis that nitrogen fertilization under low temperature (11/7C) increases N percent in plant storage organs is supported from the results of growth chamber as well as from the field experiments which were conducted in a low temperature period. However, water stress did not change the effects of nitrogen fertilizer on N contents of plants. Similar results were found by Rumburg (1969). Carter and Scholl (1964) reported that the nitrogen percent of orchardgrass and bromegrass continued to increase as plants were given up to about 115 kilograms of nitrogen per hectare.

The most important or useful result of this study, however, was the indication that the N percent of range plants is not critically affected by medium temperature (19/7C) and high water stress treatments and that the response to physical factors among plants is variable. Generalizations as to plant response to N should be restricted to those responses of individual species or even ecotypes where supporting data are available.

Thus, successful rangeland fertilization or selection of range species for fall plant production requires an awareness of temperature and nitrogen effects. Only those species like crested wheatgrass and fourwing saltbush which can utilize additional N under the environmental conditions prevailing in the fall season should be fertilized.

Carbohydrate reserves

Total nonstructural carbohydrate (TNC) reserves are considered to be an important indicator for plant vigor and plant production. Reserve substances are required for maintenance, growth and reproduction in plants. Leaves, stems and roots of both crested wheatgrass and fourwing saltbush showed a different response to experimental treatments. Roots contained the highest TNC content followed by stems and leaves. Although reserve substances are elaborated in the leaves, they are stored in stems and roots of plants (Trlica and Cook 1972).

Leaf carbohydrate percent of crested wheatgrass showed a significant reduction due to high temperature (27/7C) treatment. The cool temperature regimes (11/7 to 19/7C) slowed plant growth and high carbohydrate accumulation. McKell et al. (1969) also found the highest concentration of carbohydrate in coastal bermudagrass and Kentucky bluegrass at a cool temperature (13/7C). Auda et al. (1966) found 45 percent higher carbohydrate reserves in orchardgrass maintained under low temperature (12C) than in plants kept at a high temperature (27C).

Soil moisture is a major factor controlling growth and under stress conditions an inverse relationship between rate of growth and total nonstructural carbohydrate might be expected if growth processes such as cell division and expansion are restricted by water stress to a greater degree than is carbon fixation. Effects of water stress vary from species to species. Some scientists have reported that water stress increased carbohydrate reserves in several grass species (Brown and Blaser 1965, Blaser et al 1966), others have reported that water stress decreased carbohydrate reserves (Murata and Iyama 1963, Brown 1939, Brown and Blaser 1970, Hyder and Sneva 1959). In this study water stress treatments did not change the TNC of crested wheatgrass or fourwing saltbush.

With a moderate amount of nitrogen fertilizer (50 kg N/ha) crested wheatgrass contained more TNC in leaves, stems and roots than the plants at zero or 100 kg N/ha level. However, under field conditions 50 to 100 kg N/ha level resulted in more TNC in fourwing saltbush stems during fall growing seasons. In the following spring TNC in roots was also increased due to nitrogen fertilization (50 to 100 kg N/ha). In the growth chamber experiment fourwing saltbush did not respond to nitrogen fertilization. In the field experiment TNC in roots was highest at 50 kg N/ha but the 100 kg N/ha rate reduced the TNC in roots more than unfertilized plants. Leaves did not respond to N fertilization.

The results of the research support the hypothesis that with nitrogen fertilizer (50 kg N/ha) the total nonstructural carbohydrate (TNC) in the leaves and roots of crested wheatgrass is increased. However, as the rate of nitrogen is increased to 100 kg N/ha, the TNC percentage in plants is significantly reduced. The TNC content of fourwing saltbush is not effected by N application. Thus, successful rangeland fertilization requires a careful evaluation of N requirement for the species under study. The nitrogen fertilizer level used should be based on physiological as well as economical factors.

Soil nitrogen in the root system

Results of the growth chamber as well as field experiments showed that with the application of nitrogen fertilizer dry matter yield of crested wheatgrass and fourwing saltbush could be significantly increased. The increase in nitrogen percent of plants due to nitrogen fertilizer (50 to 100 kg N/ha) was also evident from the results of growth chamber and field experiments.

Plants absorb soil nitrogen through their root systems in the form of nitrates and ammonium. Nitrogen fertilizer applied on the soil surface is leached down into the root zone by water percolation. Thus, the amount of nitrogen, soil moisture availability and root distribution along with soil characteristics influence nitrogen uptake by plants. In addition to the environmental factors involved in the uptake of nitrogen, physiological and morphological characteristics of plants should also be considered (MacLeod 1965).

Results of the second field experiment showed that under dry conditions no significant leaching of nitrogen occurred below 10 cm soil depth. The nitrogen penetration within the top 10 cm soil depth was due to 5 mm of rainfall received two days before soil sampling for nitrogen. In the medium and wet soil moisture regime, nitrogen fertilizer transport occurred to depths of 20 to 30 cm. The soil water content under medium and wet conditions was also increased in the upper 20-30 cm of soil. Similar results were reported by Bauder and Montgomery (1980).

Results of field experiment II further revealed that under dry summer conditions nitrogen fertilizer applied at the beginning of the fall growing season would remain in the top 10 cm soil because the meager amount of rainfall percolated only to 10 cm soil depth. In this situation 35 percent of crested wheatgrass root biomass came in direct contact with the nitrogen fertilizer. On the other hand only 18 percent of total root biomass of fourwing saltbush benefited from nitrogen fertilization during fall growing season. On the basis of root distribution more dry matter production may be expected from crested wheatgrass than in fourwing saltbush plants. However, physiological and morphological characteristics of grasses and shrubs should be fully considered before any comparison of nitrogen uptake between crested wheatgrass and fourwing saltbush is made.

It is speculated that over a long period, fourwing saltbush may be a better beneficiary of fall nitrogen fertilization. Precipitation received during winter will carry nitrogen fertilizer below 40 cm soil depth where 40 percent of total root biomass of fourwing saltbush is located. In the following dry spring or summer growing seasons, fourwing saltbush would be able to exploit water and nitrogen stored in deep soil. The efficiency of crested wheatgrass, under these conditions would be only half that of fourwing saltbush because crested wheatgrass maintains only 18 percent of its total root biomass below 40 cm soil depth as compared to 40 percent root biomass of fourwing saltbush. However, further research is needed to support this speculation. In the first field experiment fall fertilization of crested wheatgrass and fourwing saltbush significantly increased the dry matter of both species in a wet fall and spring growing season.

In the second field experiment plant biomass obtained from moderately fertilized (50 kg N/ha) plants maintained at medium or wet soil moisture regimes was equal to the dry matter yield of heavy fertilized (100 kg N/ha) plants kept under dry conditions. Results of the growth chamber experiment also support the finding of field experiments.

It is therefore inferred that with a moderate amount of nitrogen fertilizer (50 kg N/ha) dry matter yield of crested wheatgrass and fourwing saltbush may be significantly increased during a normal fall growing season.

SUMMARY AND CONCLUSIONS

During 1980-81, a series of experiments was conducted in growth chambers as well as under field conditions to determine the effect of temperature, water stress and nitrogen treatments on water use efficiency, plant biomass, nitrogen content and carbohydrate reserves of crested wheatgrass and fourwing saltbush.

In a growth chamber experiment, clones of crested wheatgrass collected from the Tintic research pastures were studied. One-year old fourwing saltbush plants were obtained from the Snow Field Station. These plants were transplanted into paper cartons (10 x 10 x 20 cm) containing soils from the Tintic crested wheatgrass pastures.

Plants were grown at two moisture regimes, field capacity (-0.3 bars) and wilting point percentage (-15 bars). Plants were kept in three growth chambers to maintain three temperature regimes (11/7, 19/7 and 27/7 C). Ammonium nitrate fertilizer at the rates of 0, 50 and 100 kg of N/ha was applied at the beginning of the study. Water stress regimes were maintained by adding the amount of water lost during the last 48 hours. After 60 days, plants were clipped. These were later oven dried and weighed.

The first field experiment consisted of 15 one-meter square plots of crested wheatgrass and 15 fourwing saltbush plants, each occupying about one square meter, at the Nephi Dryland Research Station. At the beginning of the study (September 2, 1980) ammonium nitrate at rates of 0, 50 and 100 kg N/ha was applied. After 60 days, plant regrowth was clipped, oven dried and weight recorded. Spring regrowth from the same plants was harvested in the first week of June 1981.

During the late summer and fall of 1981 a second field experiment was laid out at the Nephi Station in which crested wheatgrass and fourwing saltbush plants were subjected to three soil moisture regimes (dry, medium and wet) and three nitrogen fertilizer levels (0, 50 and 100 kg N/ha). Data on above-ground and below-ground biomass, soil water content and soil nitrogen (nitrate) under different incremental soil depths were collected.

The following main conclusions can be drawn as a result of this research:

1. Nitrogen fertilization increased the water use efficiency of crested wheatgrass and fourwing saltbush. Crested wheatgrass was more efficient in water use than fourwing saltbush. A high temperature regime (27/7C) and a high water stress regime (-15 bars) also significantly increased the water use efficiency in plants.

2. Plant production in the controlled environment of the growth chamber increased as the temperature regime and soil moisture available to crested wheatgrass and fourwing saltbush was increased.

3. Nitrogen fertilization increased the plant biomass of crested wheatgrass and fourwing saltbush. Nitrogen addition substantially increased plant production under conditions of low temperature and high water stress.

4. Crested wheatgrass had a lower overall nitrogen concentration than fourwing saltbush. Leaves contained the highest N concentration followed by stems and roots of both species. Nitrogen percent in

leaves and roots increased as temperature was decreased. Water stress did not affect the nitrogen level of plants. However, nitrogen additions increased the N percentages in all three plant parts.

5. Total nonstructural carbohydrate (TNC) percent was greater in crested wheatgrass than in fourwing saltbush. Temperature treatments affected only leaves of species. Water stress did not change the TNC percent of plant parts. Low N fertilizer (50 kg N/ha) significantly increased the TNC percentage.

6. Fall nitrogen fertilization (50 to 100 kg/ha) increased dry matter yield of crested wheatgrass and fourwing saltbush during the fall and spring growing seasons.

7. Nitrogen fertilization also increased the nitrogen content in the fall and spring regrowth of both species.

8. Low amounts of N fertilizer (50 kg N/ha) increased the TNC percent in fall regrowth. No negative effects of fall fertilization were noticed on the carbohydrate percentage in crested wheatgrass and fourwing saltbush during spring regrowth period.

9. Nitrogen fertilizer (50 to 100 kg N/ha) penetrated into 20 cm soil depth in relation to medium or wet irrigation treatments.

10. Crested wheatgrass roots within top 40 cm soil depth were observed to be double the proportion of fourwing saltbush roots at the same depth. Hence crested wheatgrass benefited more from nitrogen and water application than fourwing saltbush.

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APPENDIX

Table 14. Analysis of variance for water use efficiency of crested wheatgrass and fourwing saltbush grown in growth chamber.

Source of Variation	DF	Mean Square	F
Species (S)	1	34.7	23 **
Temperature (T)	2	9.6	7 **
N-Fertilizer (F)	2	29.4	20 **
Water Stress (W)	1	15.2	10 **
S X T	2	3.3	2 *
S X F	2	0.0	00
S X W	1	2.9	2.0 *
T X F	4	0.3	00
T X W	2	0.5	.00
F X W	2	6.0	4.0 *
Error	16	1.5	--
Total	35	4.0	--

* Significant at 0.05 level
** Significant at 0.01 level

Note: Remaining interactions were non significant at 0.05 level

Table 15. Analysis of variance for dry matter yield (grams/plant) of crested wheatgrass and fourwing saltbush grown in growth chambers.

Source of Variation	DF	Mean Square	F
Total	143	1.57	---
Temperature (T)	2	26.72	334.0 **
Error (a)	6	0.08	---
Species (S)	1	0.01	0.1
Fertilizer (F)	2	20.48	204.8 **
Water Stress (W)	1	49.46	494.6 **
Reps (R)	3	0.05	0.5
S X W	1	0.35	3.5 *
S X F	2	0.78	7.8 **
W X F	2	5.24	52.4 **
S X W X F	2	0.49	4.9 *
T X S	2	0.78	7.8 **
T X W	2	12.95	129.5 **
T X F	4	2.88	28.8 **
T X S X W	2	0.82	8.2 *
T X S X F	4	1.44	14.4 **
T X W X F	4	1.68	16.8 **
T X S X W X F	4	0.87	8.7 **
Error (b)	99	0.10	---

* Significant at 0.05 level
** Significant at 0.01 level

Table 16 . Analysis of variance for nitrogen content in leaves, stems and roots of crested wheatgrass and fourwing saltbush grown in growth chambers.

Source of Variation	DF	Mean Squares		
		Leaves	Stems	Roots
Species (S)	1	0.06	0.72 *	3.07 **
Temperature (T)	2	1.07 **	0.03	0.13 **
N-Fertilizer (F)	2	2.32 **	0.70 **	0.39 **
Water Stress (W)	1	0.08	0.00	0.04
S X T	2	0.09 *	0.08 **	0.05 *
S X F	2	0.12 **	0.05 *	0.07 *
S X W	1	0.01	0.00	0.02
T X F	4	0.01	0.03	0.01
T X W	2	0.30 **	0.02	0.03
F X W	2	0.11 **	0.02	0.03
Error	16	0.02	0.01	0.01
Total	35	0.24	0.08	0.13

* Significant at 0.05 level ** Significant at 0.01 level
All the remaining interactions were nonsignificant at 0.05 level

Table 17. Analysis of variance for TNC content in leaves, stems and roots of crested wheatgrass and fourwing saltbush grown in growth chambers.

Source of Variation	DF	Mean Squares		
		Leaves	Stems	Roots
Species (S)	1	2.33 **	2.20 **	2.01 **
Temperature (T)	2	0.06 **	0.01	0.01
N-Fertilizer (F)	2	0.03 **	0.03 **	0.12 **
Water Stress (W)	1	0.01	0.01	0.01
S X T	2	0.03 **	0.01	0.01
S X F	2	0.02 *	0.01	0.02 *
S X W	1	0.15 **	0.16 **	0.26 **
T X F	4	0.01	0.00	0.01
T X W	2	0.01	0.01	0.01
F X W	2	0.01	0.01	0.01
Error	16	0.01	0.01	0.01
Total	35	0.08	0.07	0.08

* Significant at 0.05 level ** Significant at 0.01 level
All remaining interactions were nonsignificant at 0.05 level

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Dissertation: Fall regrowth of Crested Wheatgrass and Fourwing Saltbush -

PERSONAL INFORMATION:

Born at Distt. Jhang, Pakistan; son of Mr. and Mrs. Shahamand Khan. Unmarried.

EDUCATION:

Attended primary and middle schools in Kaluwala, Distt. Jhang and graduated from Government High School Jhang in 1966. Received the Fellow of Science from Government College Jhang in 1968 and the Bachelor of Science degree from the University of Peshawar, with a major in Forestry in 1971; received the Master of Science degree in Range Science with a major in Range Management and minor in Watershed Science from Utah State University, Logan, Utah in 1980.

PROFESSIONAL EXPERIENCE:

Graduate Research Assistant (June 1977) to April 1981)

Completed requirements for M.S. and Ph.D. in Range Science at Utah State University, Logan, Utah.
Two month study tour of Rangelands of western United States.
Ecosystem Reconstruction project research on grasses and shrubs-reviews of seed physiology and germinations.

Assistant Director of Research/Research Officer (November 1974 to May 1977).

Worked in the Directorate of Range Management and Forestry, Agricultural Research Council of Pakistan Islamabad. The specific range management research work included:

Inventory and Development of Khaire Murat Range Project.
Integrated soil and vegetation survey of Quetta-Pishin.
Development of National Forage and Fodder Research Program, monitoring and evaluation.
Work related to range desert research.
Germination, introduction and establishment of indigenous and exotic grasses, shrubs and trees.
Wheat-legume rotation trials under dryland conditions.

Forest Ranger (September 1969 to October 1974)

During B.S. Forestry training at Pakistan Forests Colege, participated in:

One month field engineering course at Military College Risalpur.
Two month forest surveying and engineering camp at Dadar.
Two month forest camp at Baragali to prepare plan for conifer forests.
Two month study tour of Bangladesh tropical forests.
One week workshop on Rural Sociology at Comilla Rural Academy, Bangladesh.
One month study tour of tropical forests of Pakistan.
One month study tour of Himalayan Conifer forests.

On completion of B.S. in Forestry worked in Forest-Range Research Division, Pakistan Forest Institute. Conducted studies/research on:

Range rehabilitation through artificial reseeding.
Methods and techniques of reseeding.
Sand dune rehabilitation.
Clipping studies under range conditions to test effects of different intensities of use, different frequencies of use, interactions amongst them as well as with seasons.
Range resource surveys (reconnaissance, extensive as well as intensive surveys in Baluchistan, Punjab and N.W.F.P. provinces of Pakistan.
Range nutrition studies by conducting digestion trials on sheep in different vegetation zones and seasons.
Soil conservation practices.
Selection of superior range plant straints for range reseeding.
Range ecological studies in different major range areas.